KamLAND Off-Axis Calibration System

Technical Design Report

KamLAND 4π Design and Development Group

November 24, 2003

DRAFT – v0.3

Abstract

This document describes the design and specifications of a novel KamLAND off-axis calibration system, also known as the KamLAND 4π system. We give an overview of the functionality and features of this system as well as the development, prototyping, and fabrication. The safety features of this system are discussed and an installation and commissioning plan outlined. The most recent version of this document can be found at:

`http://kamland.lbl.gov/internal/4pi/design_report/`

With contributions from

S. Abbott,
B. Berger,
P. Decowski,
D. Dwyer
S.J. Freedman,
B. Fujikawa,
M. Galloway,
F. Gray
K.M. Heeger,
J. Meyer,
J. Learned,
K.-B. Luk,
Y. Minamihara,
B. Perry,
M. Rosen,
H. Steiner,
T. Walker,
L. Winlsow

For comments, corrections, and suggestions please email `MLGalloway@lbl.gov` and `KMHeeger@lbl.gov`.

Contents

List of Figures

List of Tables

1 Summary and System Overview

An off-axis calibration system for use in KamLAND is under development. The system consists of a segmented pole suspended from two cables with a calibration source attached to one, or possibly both ends. The pole will be assembled in the glovebox and deployed through the 6-inch opening of the existing glovebox. It is controlled by two control cables. The deployment systems for this calibration device will be housed in the existing glovebox, with an extension to accomodate the additional hardware. For a schematic illustration of the system see Figure 1.

The calibration pole will allow the off-axis placement of passive calibration sources. The system can be deployed in two different modes.

1. In the *symmetric configuration*, the calibration pole is deployed with the control cables attached to the ends of the pole.

2. Using a counter weight inside the last segment of the calibration pole and with one control cable recessed from one end of the pole the system can be deployed in an *asymmetric mode*.

We envision that this system will allow the calibration of detector volumes out to R$\leq$ 6 m. The position of the calibration pole will be determined by means of 3 independent sensor devices:

1. Encoder pulleys in the glovebox measure the length of the control cables and/or straps and provide real-time information for the motor winch system.

2. Pressure transducers at either end of the pole measure the depth of pole and provide information on the absolute depth of the pole as well as the relative z-position and incline of the calibration pole. Depth information with an accuracy of ~ 1 cm can be obtained.

3. Imaging of the infared LEDs attached to the segments of the calibration will provide an accurate off-line determination of the pole position. In preliminary tests a positioning accuracy of $\sim$ 3 cm has been achieved.

For a list of materials used for this system see Appendix B. The results of readioassay tests is summarized in Appendix C.

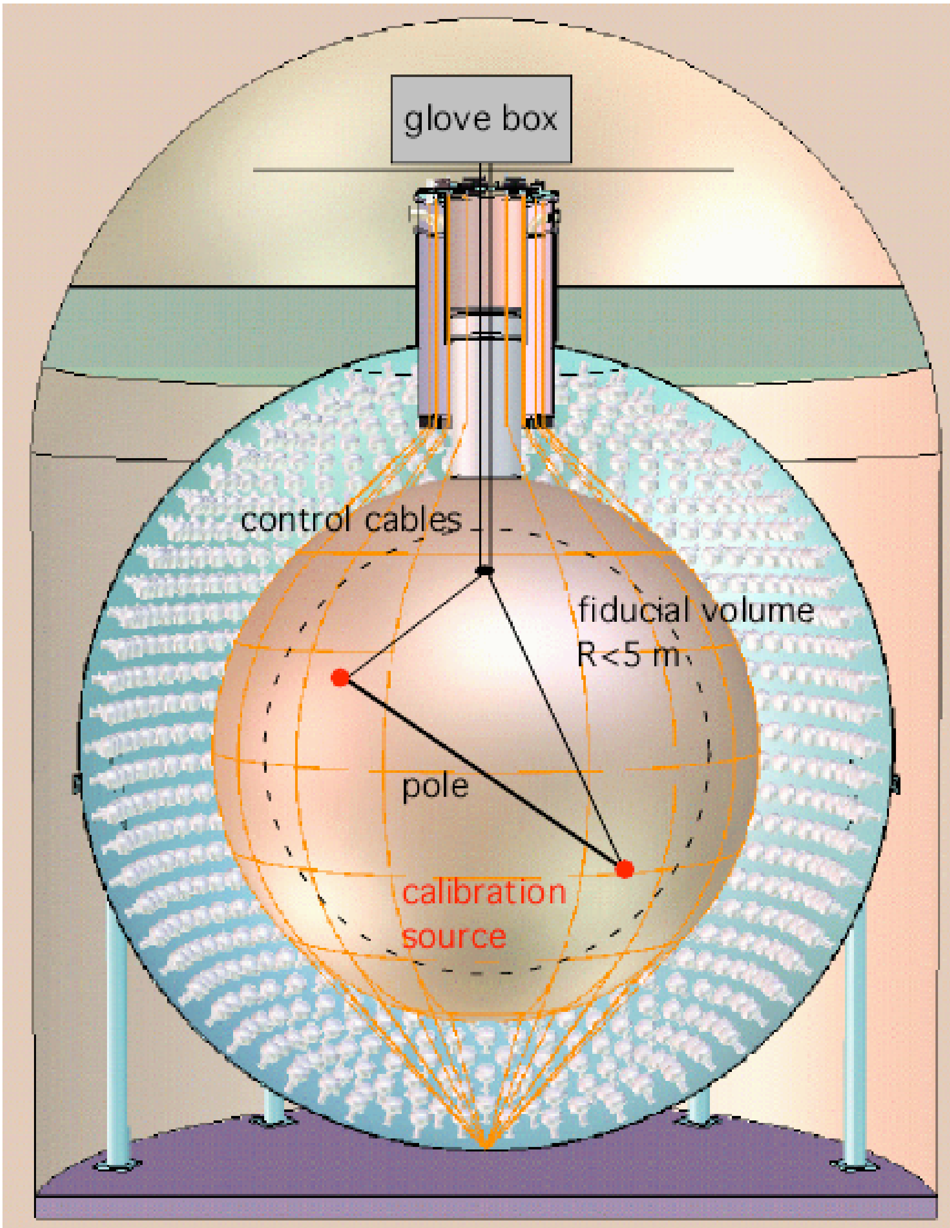


Figure 1: Overview of the calibration pole in the KamLAND detector system.

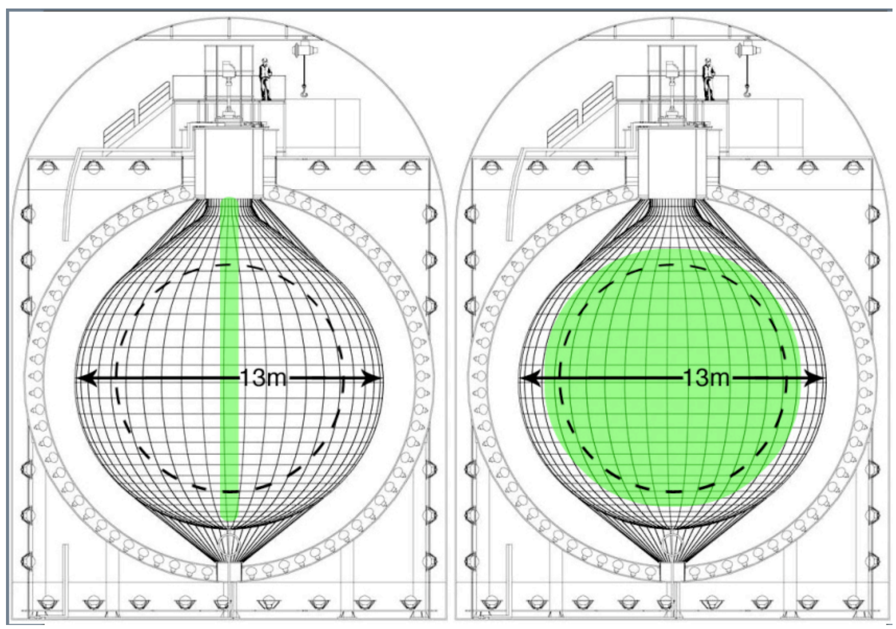


Figure 2: Illustration of the fiducial volume reach of the z-axis and the new off-axis KamLAND calibration system.

2 Functionality of the Off-Axis Calibration Systen

The off-axis calibration system under development will allow the placement of passive calibration sources in the entire detector volume within a radius of 6 m. The purpose of this system is to

- provide off-axis calibrations with minimal interference of the detector and its systems
- safely deploy and retrieve passive calibration sources
- allow for an accurate position determination of the source
- adjust the radial and angular position of the calibration source
- provide redundant monitoring safety measures

2.1 Deployment and Retrieval of Calibration Sources

The main purpose of the system is the deployment of passive calibration sources in the inner detector volume. Source attachment points identical to the ones used in the existing z-axis system are provided. A control system allows the placement of calibration sources in the entire detector volume.

2.2 Positioning in R, θ, ϕ

The radial position of the source can be changed in two different ways:

1. In the *symmetric mode* the number of tube segments used in the assembly of the pole defines the radial position of the calibration source. The minimal number of segments is 1. The system allows for a maximum of 8 tube segments.
2. In the *asymmetric mode* there are two ways to change the radial position of the source. As in case 1, we can vary the number of pole segments. In addition, we can change the radial position by adding extra weight to one end of the pole. This weight shifts the center of mass away from the geometric center of the pole. This allows the overall length of the pole to be minimized to approximately 8m/24'. It also requires less storage in the glovebox and

simplifies the assembly required to change the radial positioning. See Section 71 for a physical description.

The θ position of the pole and the source can be changed by adjusting the length of the control cables. The existing rotary stage can be used to control the ϕ position of the glovebox, and hence the calibration pole.

2.3 Position Determination

Three independent techniques will allow real-time monitoring of the system as well as accurate position determination off-line:

1. Encoder pulleys measure the length of the control cables.
2. Pressure transducers provide information on the depth of the calibration pole and the z-position of the ends.
3. Imaging of infrared LEDs attached to the pole allow the accurate off-line reconstruction of the calibration source position.

2.4 Monitoring and Safety Measures

Several independent techniques allow the monitoring and control of the system. Manual emergency operation in addition to the computer-controlled routine operation ensures that this calbration device can be retrieved from the inner detector. The simplicity of the design minimizes the interference with the detector and the displacement of liquid scintillator. It also reduces the risk of operating failures.

3 Physics Goals and Objectives

4 System Hardware

4.1 Pole Segments and Couplings

4.1.1 Materials and Fabrication

The pole is assembled using 3 AL 2.5 V titanium tubing. Each segment is approximately 1 m/ 36" in length. The outer diameter of the tubing is 1.5" with a wall thickness of 0.039" +/- 0.004". The prototype is presently manufactured from 304 stainless steel of similar dimensions. Deflections and buckling forces were calculated assuming a pole suspended horizontally with two ends simply supported. See the following table for material specifications:

Table 1: Characteristics of stainless steel and titanium for a pole supported at both ends.

	Material	
	304 Stainless Steel	3A12.5V Titanium
Density (lbs/inch^3)	0.285	0.163
Youngs Modulus (psi)	2.9×10^7	1.74×10^7
OD (inch)	1.500	1.500
Wall Thickness (inch)	0.039	0.039
Length (ft)	24	24
Volume (inch^3)	51.53	51.53
Total Mass (lb)	18.19	10.40
Inertia (inch^4)	0.0478	0.0478
Buckling Force (lbs)	164.68	98.81
Deflection (air, inch)	4.08	3.89
Displacement (m^3)	0.007826383	0.004476142

Titanium is chosen because it minimizes the per segment weight and the overall assembly weight. This results in less of a counterweight needed to change the radial position. The low weight makes it easy for a gloved operator to handle.

The number of segments used in assembly is currently 8 segments. This number may vary according to the radial position desired, and the amount of weight added to one end. This is explained in more detail in the radial positioning Section **??**.

Premanufactured bicycle torque couplings are welded to the ends of each tube to allow easy alignment and coupling of the segments. These couplings have castellations to allow precise mating of the two pieces. A movable sleeve on the end of one segment fits over the threads of the next segment. A torque wrench is used to join the couplings with a force of approximately 25 ft-lbs. Retaining rings keep the sleeve secured on the tubing segments. Mineral oil of the same grade as the scintillator will be used as a lubricant on the threads to prevent galling.

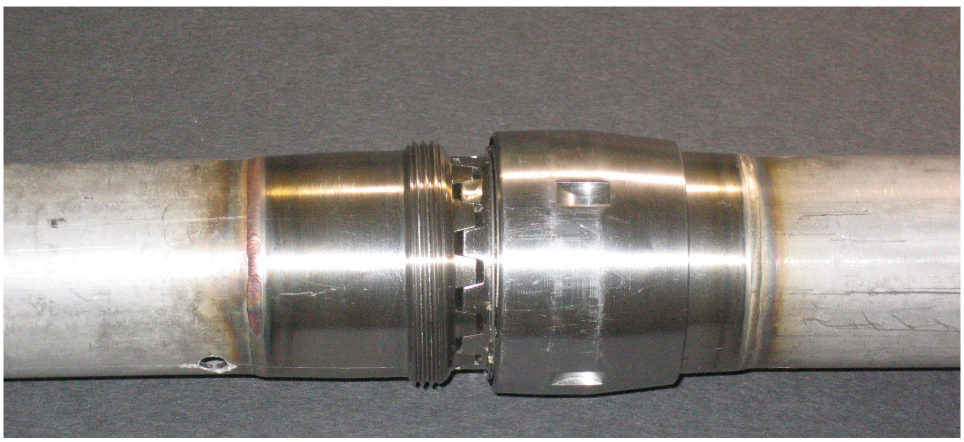


Figure 3: Photograph of Bicycle Torque Coupling (BTC) welded to a 1.5" inch outer diameter tube.

The couplings are machined for an interference fit into the inner diameter of each tube. TIG weldment using a zirconium tungsten electrode is used on the inner and outer surface joint to ensure a structural and hermetic attachment between the coupling and tube. The inner weld is to prevent trapping of contaminants. This is a fusion weld, no filler metals are added.

An alignment fixture is used during the welding process. This fixture utilizes the castellations of the couplings to ensure that the individual segments when assembled will allow the whole structure to be aligned from end to end within two degrees. Some kind of visual fiducial will also be implemented to keep this alignment throughout the assembly process.

Titanium samples from the lot of tubing and couplings to be used in the final assembly have been counted for radioactive content with satisfactory results. See the Appendix for further details C. Further testing in a weak acid soak is required. Radioassay of the zirtung electrodes previously qualified this type of electrode for use in the SNO detector. This replaces the standard thoriated tungsten electrodes.

4.1.2 Specialized segments

One end of the pole will hold the source. A BTC will be welded to a rod for the source attachment. This attachment will be identical to the present z-axis source attachment, so that any of the existing sources can be used on the 4pi system. The assembly of this specialized end segment to the calibration sources will take place in the source preparation area prior to installation.

The end of the pole opposite the source end will be deployed last and retracted first under normal operation. This end piece is comprised of a short BTC segment with one of the motion control cables permanently attached. This is the top cable in the glovebox, which is deployed directly on the z-axis of the detector. A specialized BTC with a hook attached to one end will be used as a hoist to aid in the assembly procedure. This section will couple to the top cable BTC during assembly.

Approximately 3 segments will be made, each of a different mass. They will contain rods of stainless steel and/or tungsten. These segments will be 1m/36" in length, identical to the rest of the segments aside from the internal weights and a label to signify its respective mass. The weights will be constrained along the length of the tube, but the outer diameter of the cylindrical weight inserts will be slightly less than the ID of the tube segments. This allows a rotational freedom of motion of the mass within the tube to act as a ballast. This provides a more controlled descent, and allows the pole to stabilize itself.

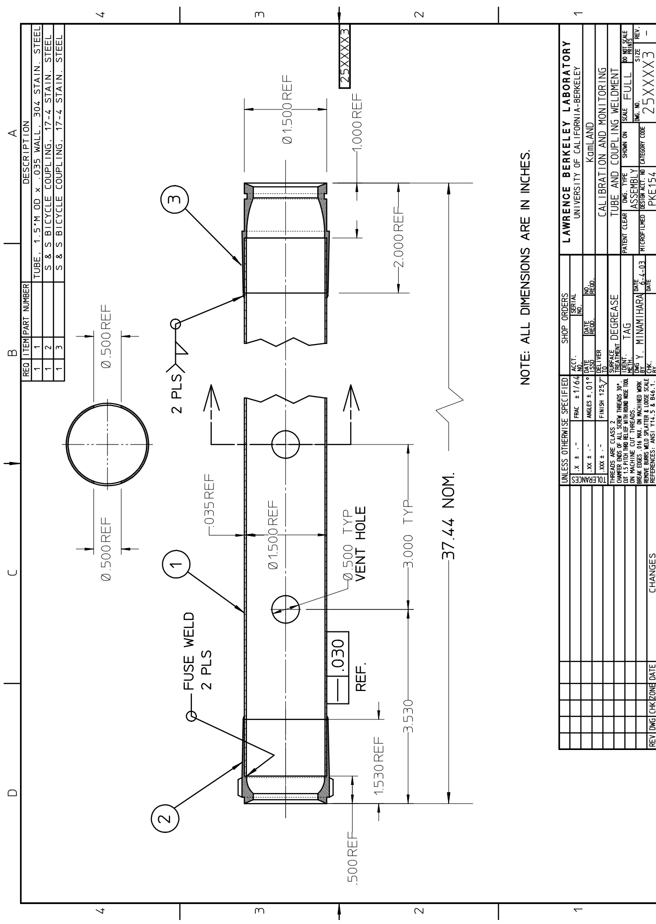


Figure 4: Technical drawing of a welded tube segment. Note: The weldment drawing is for the stainless steel couplings which fit onto the OD of the tube. The titanium couplings fit in the tube ID.

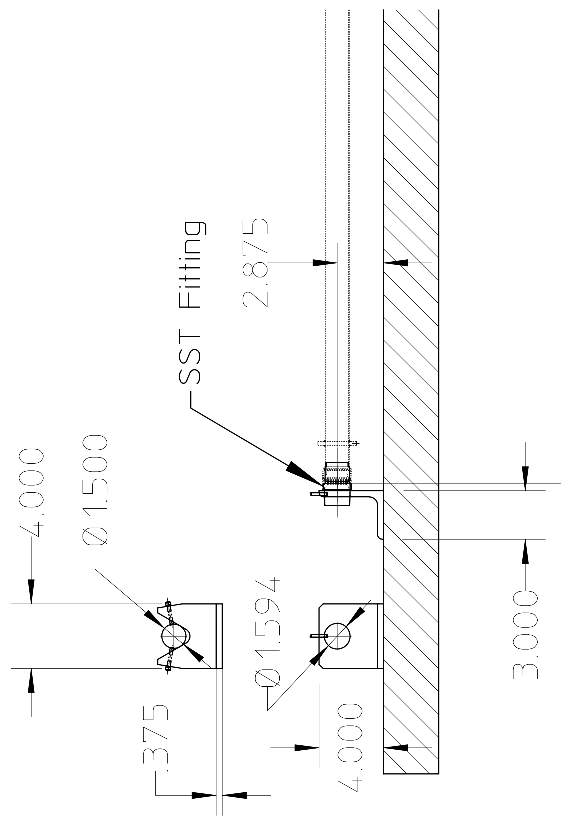


Figure 5: Procedure for aligning the couplings during welding

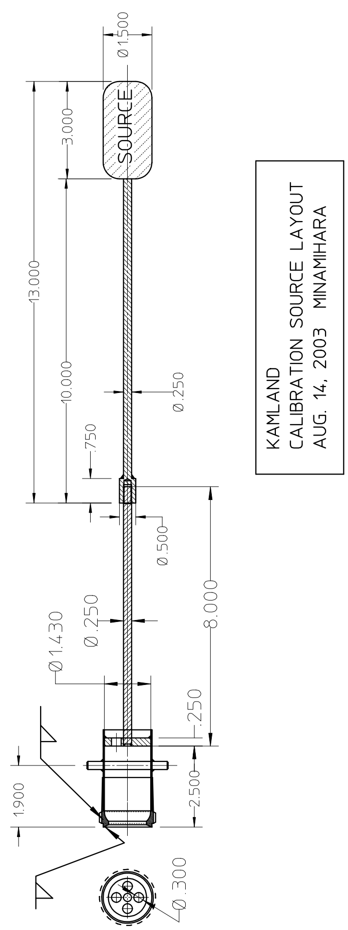


Figure 6: Technical drawing of the source holder.

4.1.3 Internal Safety Cords

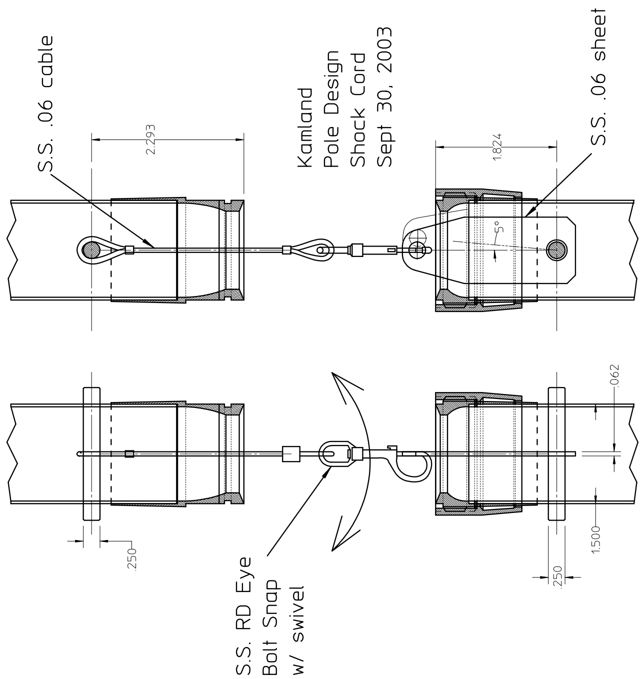


Figure 7: Preliminary design for internal safety cords

Each segment will be equipped with an internal cord to serve as a safety mechanism to couple one tube to the next. The function of the internal cord is to serve as a back-up during assembly or in a BTC failure mode. It is also used as a hoist attachment during assembly. One end of each segment (the male coupling side) will contain an eyebolt or D-shaped ring. The other end will secure a lanyard which holds a clasp, or carabiner mechanism. This attachment between two segments is made prior to the BTC assembly. The overall length of this cord is approximately 5", and it resides within the interior of each segment. (See deployment protocol **??**). The final configuration of the internal cord mechanism will be designed for easy assembly by a gloved operator. It will also be designed to prevent loose parts. The first two segments may have a longer internal cord, to allow attachment between segments while they are still hanging in the glovebox rack. This provides an additional safety before the first cable is attached to the assembly. The details of incorporating this extra safety are to be determined. In the current deployment protocol, it is written that each of these two initial segments contains two internal cords each. One is a long cord for a safety during assembly, the second cord is a short cord to retain the two segments in the event the assembly comes apart in-situ. We are currently looking into having an external cable run along the first three segments which contains conductors for a pressure transducer very close to the source, and a stainless member to serve as the safety for the first few segments during assembly (tbd).

4.1.4 Dowel Pins

Each of the standard segments and the weighted segments will have three 0.25" diameter dowel pins inserted and welded into the cross-section of the tubing. One pin will be approximately 2" from the end of the segment which has the female side of the coupling. The length will be the same as the outer diameter of the tubing at 1.5" so the ends of the pin are flush with the tubing (shown longer in drawing). It's function is to hold the clasp or hook end of the internal cord. The second pin will be approximately 2" from the end of the segment which has the male side of the coupling. The length will be approximately 3". It is used to provide torque restraint while joining the coupling, as a safety to keep the segments from falling through the 6" flange, and to hold the eye hook end of the internal cord. It is also used in pre-assembly to hang the segments in the glovebox storage rack. A third pin will be welded into position 1.5" below the second pin (3.5" below the end of the male coupling), and of the same length as the second pin. It serves to stabilize the pole during assembly, and as an additional safety to keep the segments from falling through the 6" flange. The second and third pins will be long enough to exceed the coupling outer diameter and provide safety and torque restraint. However, the edges

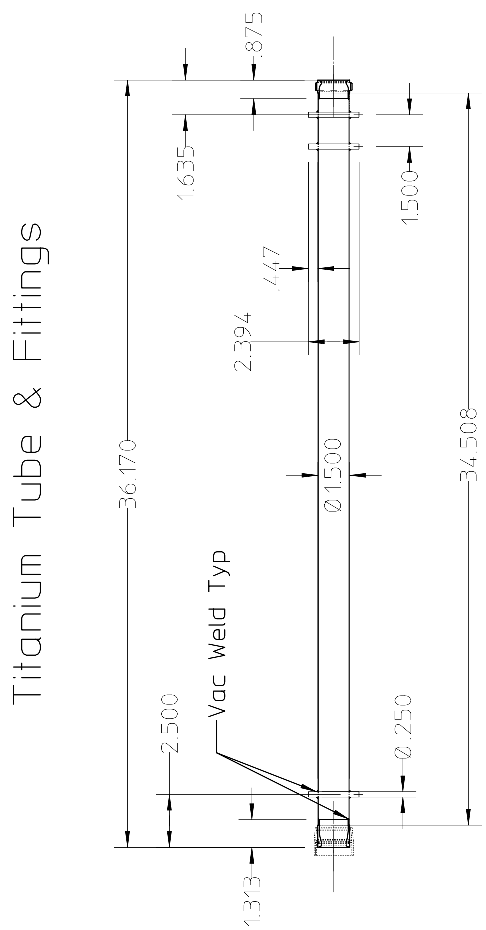


Figure 8: Technical drawing of titanium tube with pins

will be significantly rounded so as to avoid interference with cables. The weighted segments may have additional pins to constrain the internal weights. They will be 1.5” in length. The source segments and the hoist segment will have the second and third pins only, with the eye hook extension of the internal cords. The top cable end segment will have just the first pin and lanyard.

4.1.5 Damping Modifications

Based on further prototyping (water tests) and modeling efforts, changes may be made to the tubing to dampen any oscillations of the pole. This will most likely include additional holes drilled into the cross section of the tubes to decrease motions in the fluid. The tube assembly is open on both ends to allow slow oil filling of the structure during deployment. Holes will be drilled through the cross section of each segment end to eliminate any internal areas which may trap air. The perforations, in combination with a slow descent (1- 12 cm/s), should diminish bubbling effects and air trapping within the pole. The initial deployments (and perhaps all deployments) will be monitored visually using the LEDs on the pole and the detector CCD cameras. This will give us a time estimate for the stability in position of the calibration source. This information will form the basis of overall time required for obtaining calibration data.

4.2 Cabling

Two cables are used to support the pole, control its motion through deployment, angular positioning in θ, and retraction, and supply the voltage and signal feedback requirements of the system. Currently a custom cable is being manufactured by a company called Woven Electronics.

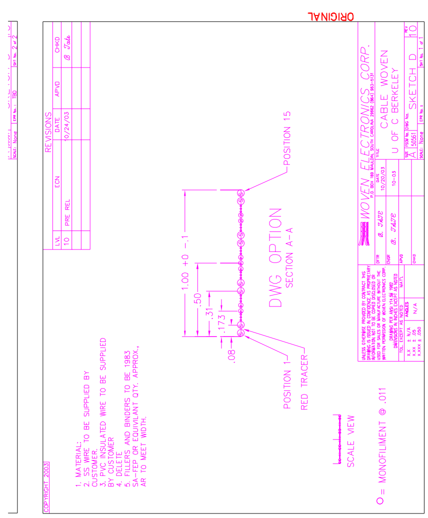


Figure 9: Technical drawing of custom cable from Woven Electronics.

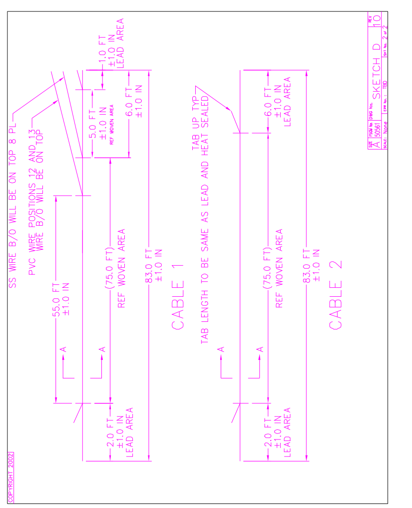


Figure 10: Technical drawing of custom cable from Woven Electronics.

4.2.1 Mechanical Requirements

A load bearing member is necessary in the cable configuration to support the weight of the tube. Stainless steel wire is being used due to its high tensile strength, minimal elongation, and compatibility with the scintillator. Eight strands of 7x19 stainless steel wire rope of diameter 3/64" are being woven into the custom cable. Each strand has a breaking strength of 160 lbs. The stainless wires will be pretensioned and fixed at both the spool ends and the pole ends to provide the mechanical support of the pole. Four of the eight strands will be used to support the cable at the fixed side of the pivot block. Methods and testing procedures for these attachments are currently under development. An initial cleaning and testing of a sample of this wire rope was done using a 909 cleaner (ultra high vacuum cleaning procedure). The sample was tested for cleanliness using GCFID method, and no hydrocarbons were detected above the detection limit of 4 ppm. An uncleaned sample contained about 65 ppm of hydrocarbons.

4.2.2 Electrical Requirements

The position sensors on the pole require voltage and a signal output. Seperate conductors can be used for each voltage, ground, and signal line, or just two cables can be used in conjunction with circuitry to multiplex the signals. See 7.1 for more information. LEDs can also be powered by the same voltage, utilizing voltage dividers at the end of the conductive cable, or powered by batteries. The woven cable includes 7 strands of teflon coated 30 AWG conductive wire.

4.2.3 Flat Ribbon Cable

The woven cable will be similar to a flat ribbon cable. It will be 1" in width and approximately 0.090" in thickness. Monofilament will be interwoven with the wire rope and conductors to obtain the 1" width. Monofilament is also used as the lateral weave material. The flat cable provides necessary stability to the system. Prototype tests have shown that the flat cable eliminates any spinning motion of the pole, especially when it is in the vertical position.

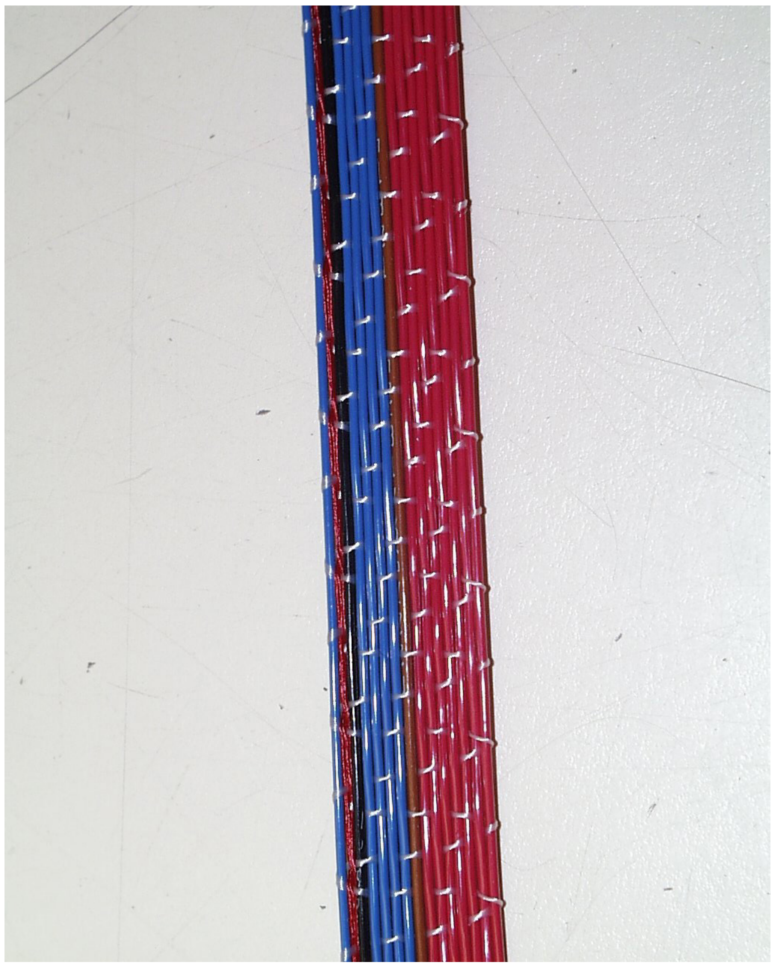


Figure 11: Photograph of sample cable from Woven Electronics.

4.2.4 Round Braided Cable

A round braided cable has been tested with the prototype. The braided cable also maintained torsional stability throughout vertical deployment and positioning. A company called South Bay Cable produces circular composite cables. A polyurethane coated BNC cable with a braided kevlar strength member inside will meet our mechanical, electrical, and material compatibility requirements. Two of these cables have been purchased as a back up plan to the woven, flat cable.

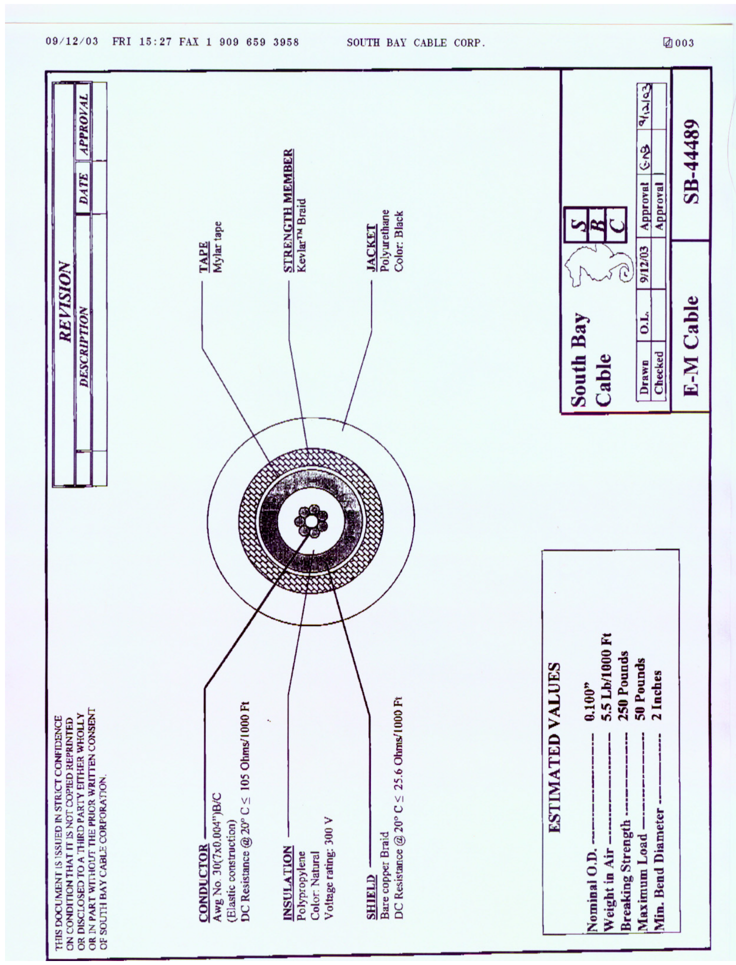


Figure 12: Technical drawing of South Bay cable.

4.2.5 Cable combinations

Depending upon testing and development results, flat ribbon cable may be used for both cables, or a combination of the ribbon cable and circular cable may be used. Two round cables side by side to support one end may also be a possibility.

4.2.6 Cabling Hardware

Each of the cables is contained on an anodized aluminum spool which is directly coupled to the shaft of each motor gearhead (see **??** for motor description). As the cables are despooled by the motor, they are routed over a guide pulley. This pulley is fixed upon a rotating shaft and will be constructed of either teflon or delrin to have minimal friction. The cable is constrained between the guide pulley and a small idler pulley. The idler pulley serves to keep the cable from slipping on the guide pulley to ensure an accurate reader of the encoders (see 7.2). The encoder is directly coupled to the shaft of the guide pulley and is encased in a separate housing to satisfy material compatibility requirements.

The top cable pulley is approximately 45" above the top of the pinblock to allow a full segment to be supported by the top cable during assembly. Both pulleys are designed to be adjustable in position for alignment and emergency purposes.

4.2.7 Terminations

Terminations of the cable ends will be made by seperating the strength members from the conductors at both ends of the cable. The SS wire rope will be firmly attached to the inside of the spool. A pretensioning process is currently being developed to ensure each of the stainless wires in the cable are attached at both ends at the same length to provide even distribution of load.

An encased electrical slip ring is incorporated into the ID of each spool to allow the electrical cables to remain connected throughout the motion of the spool. The seven conductors are routed through a channel to the center of the spool and connected to the slip ring. At the pole end, we are currently in the process of testing watertight connectors and liquid tight strain reliefs. Probably some qualified epoxy may be needed to coat any exposed solder connections.

4.2.8 Attachment to the Pivot Block

The source end cable will need to be attached at one point along it's length to the pivot block (see the next section). We are currently looking into laser welding a grommet onto 4 of the stainless steel wire ropes to attach to the pivot block. This will be in addition to a clamp at the pivot block. This grommet will need to be small and smooth enough to not interfere with overlapping cable wound onto the spool. Any protrusion from this piece will be on the outside of this cable, meaning, it will be on the opposite side of the cable contact with the guide pulley so it will not interfere with encoder readings. The cables will need to be adequately marked to indicate to the operator the correct attachment point to the pivot block.

4.3 Pivot Block

The pivot block has two functions. It is a constraint on the two cables to hold them at a distance of about 1" apart as the pole is deployed from the glovebox to the center of the detector. It is also the pivot point which allows one cable length to vary while stabilizing the other cable, thereby changing the altitude and direction of the source.

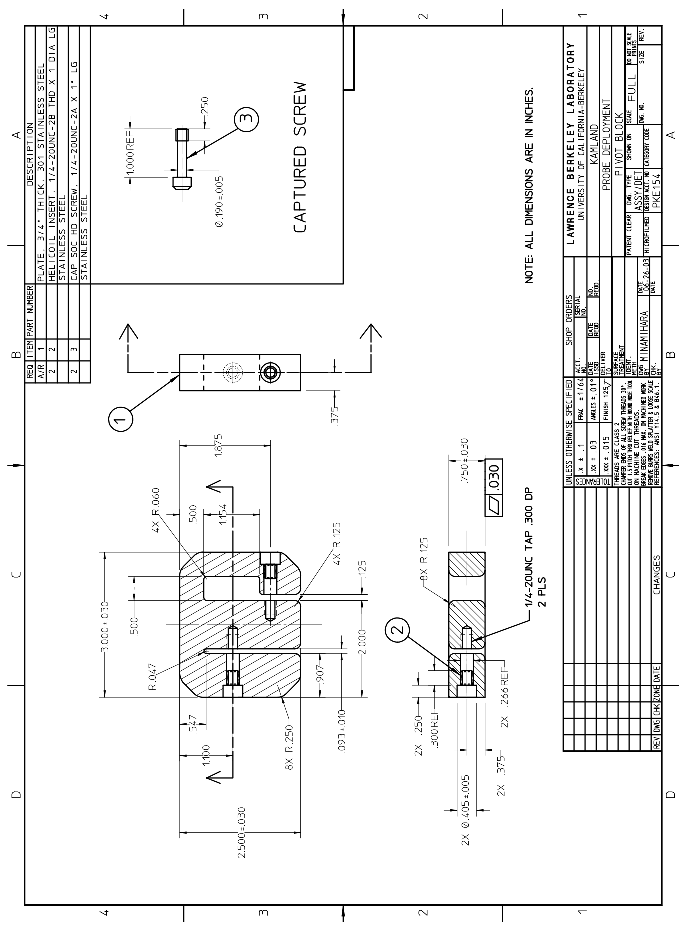


Figure 13: Technical drawing of first pivot block design.

The cable on the weighted end of the pole (opposite source end) is attached to the pivot block at a fixed position. This position is approximately the length of 7 segments, about 7m/21' from the weighted end of the pole. This keeps the pivot block at a safe distance below the neck of the detector during calibrations. The other side of the pivot block is made to reduce friction, so as to allow the source end of the pole to lower as the cable is dispensed. The current prototype contains a teflon roller with ball bearings press fit onto a shaft. The pivot block is being designed to make assembly easy for gloved users and without loose parts. It currently contains two captive bolts, plus a toggle bolt for clamping. The two bolts which are on the side plate are detached from the body of the pivot block. This piece is attached to a pin on one end of the pivot block which allows the piece to swivel out of the way to load in the cables. The pivot block contains no loose parts.

A method for attaching a pressure transducer to the pivot block is being investigated. One of the woven cables being made has two conductors which break out of the main weave at the position where the pivot block is attached. We may be able to attach two non-intrusive gold pins to these conductors which will plug into the pivot block at the time of its attachment.

4.4 Pin Block

The pinblock is a cover for the 6" flange on the bottom of the glovebox. Its function is to keep objects from falling into the detector during assembly, and to provide a safe way to assemble, lower, and retract the pole structure piece by piece.

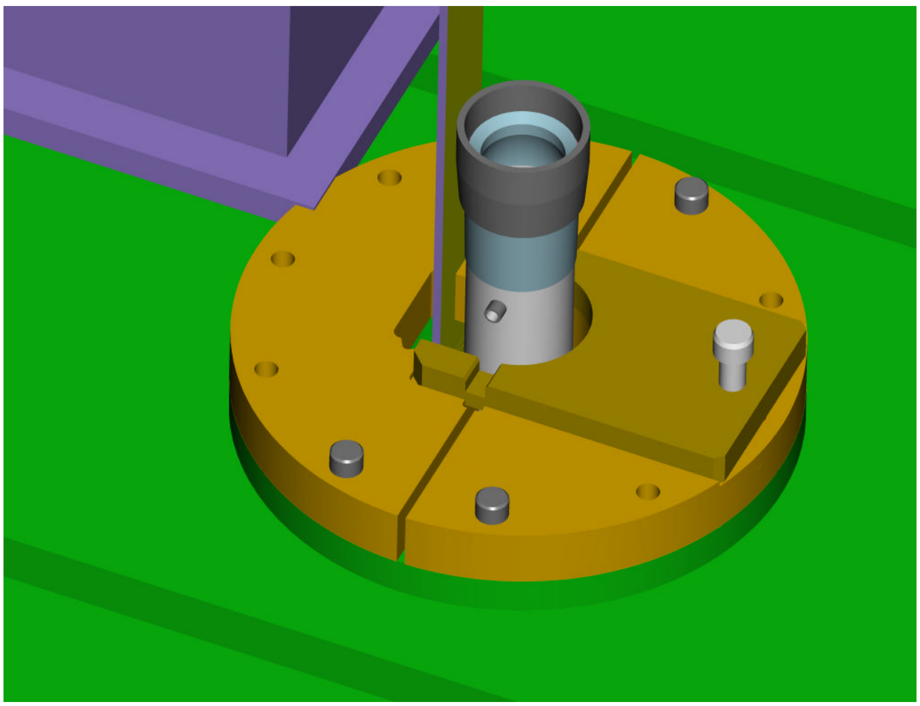


Figure 14: Layout of pin block with safety step.

4.4.1 Pin Slots

One slot protrudes above the surface of the pinblock. It holds the pin of each segment in place, providing torque restraint during coupling. A slot at a 30 degree angle from the torque slot allows the segment to begin to pass through the pinblock. The user lifts the segment out of the torque slot and rotates it 30 degrees CW to place it into the pass through slot. Underneath this slot is a step which requires the user to rotate it 30 degrees CCW to lower its position. Both pins need to be rotated through the pinblock before a segment can pass through the 6" flange completely. The first pin on the male coupling of each segment is lowered below the pinblock for stabilization during coupling. Once the coupling is secure, the above procedure is repeated to lower the assembly.

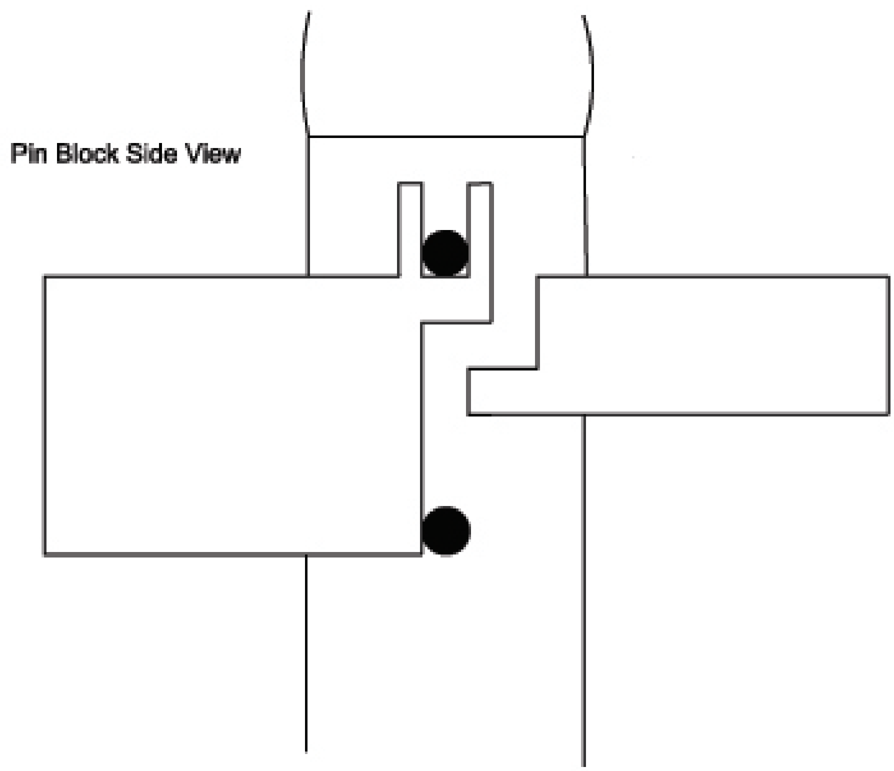


Figure 15: Sideview of pin block with double pin of pole segment.

A sliding pin plate is utilized on top of the pinblock. Its two functions are to allow the pivot block to pass through the flange, and to allow easy retraction of each segment. The sliding pin plate is activated by pulling up on a knob and sliding it away from the center of the flange. This exposes an opening which is large enough to accommodate the pivot block and the segment pins. It is spring loaded which greatly minimizes the chance of accidental opening. Two guide plates which are welded underneath the pinblock are incorporated into the design to avoid extreme angular insertion of the segments. The plates are 3 3/16 apart (both about 1.6 from the center of the pinblock), about 13 long, and are affixed in the same orienation as the pins. They are slightly curved at the ends to ease re-entry of the pivot block and pole assembly. These guide pieces will be positioned inside the 6" spool below the glovebox, and above the 6" gate valve. The 13" length was chosen so that any sideways motion of the pole during assembly will not in any way allow the source end to come into contact with the sides of the spool. The width was chosen to allow enough room for the pivot block to pass through and be retracted easily. The primary component of the pinblock consists of two semicircles which together cover the 6" flange. The two pieces fit together allows for emergency removal of this flange cover to access the spool interior without interfering with deployment cables or segments.

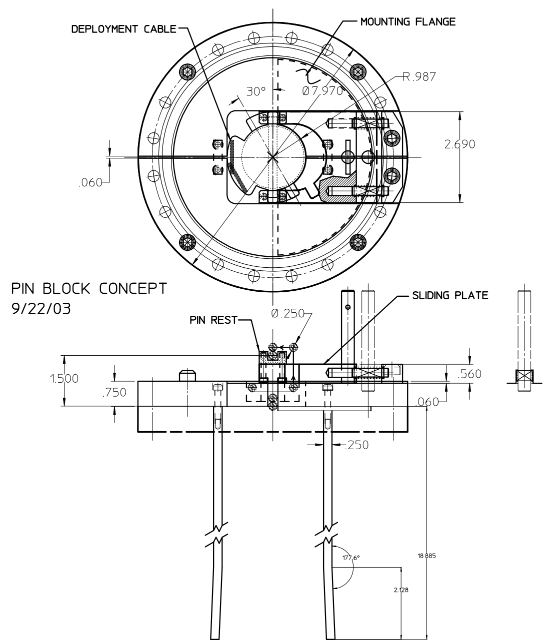


Figure 16: Technical drawing of pinblock

4.5 Glovebox Modifications

The present z-axis glovebox will be modified to accomodate the 4pi system.

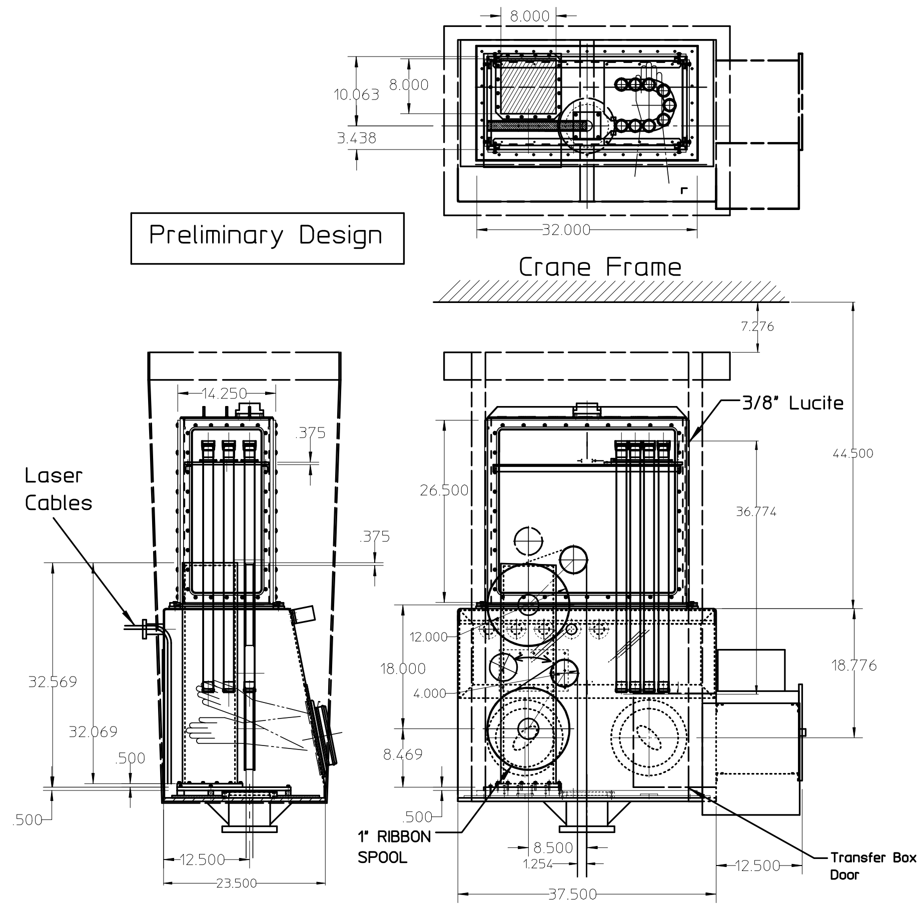


Figure 17: Technical drawing of the extension to the glove box.

The addition of a second story unit to the top of the existing glovebox will increase the vertical dimension by 26.5". It is comprised of a stainless steel frame with acrylic panels. The acrylic provides visibility during the assembly process. The panels are bolted to the frame and sealed with viton o-rings. An external, removable light-tight cover will be made of neoprene. The glovebox addition provides a rack for the segments. The vertical dimension was chosen to accomodate the 36" segments. The rack which holds the tube segments is positioned low enough so that the operator can access the bottom of the segments. Clearance underneath the storage rack was given for opening and closing of the transfer box door. Two gloveports will be added to the top unit. They will be on the opposite side of the glovebox as the present gloveports. This will allow a second operator to access the hoist and the top of the tubes during assembly. The two motors will be mounted onto a baseplate on the bottom of the glovebox. They will be sealed in a stainless steel housing. All electrical ports will be hermetically sealed and of compatible materials. Two spools for the cables, plus thier respective guide pulleys, idler pulleys, and encoders will also be supported from this baseplate. It is designed to align the top cable directly on the z-axis of the detector. This system will temporarily replace the z-axis system.

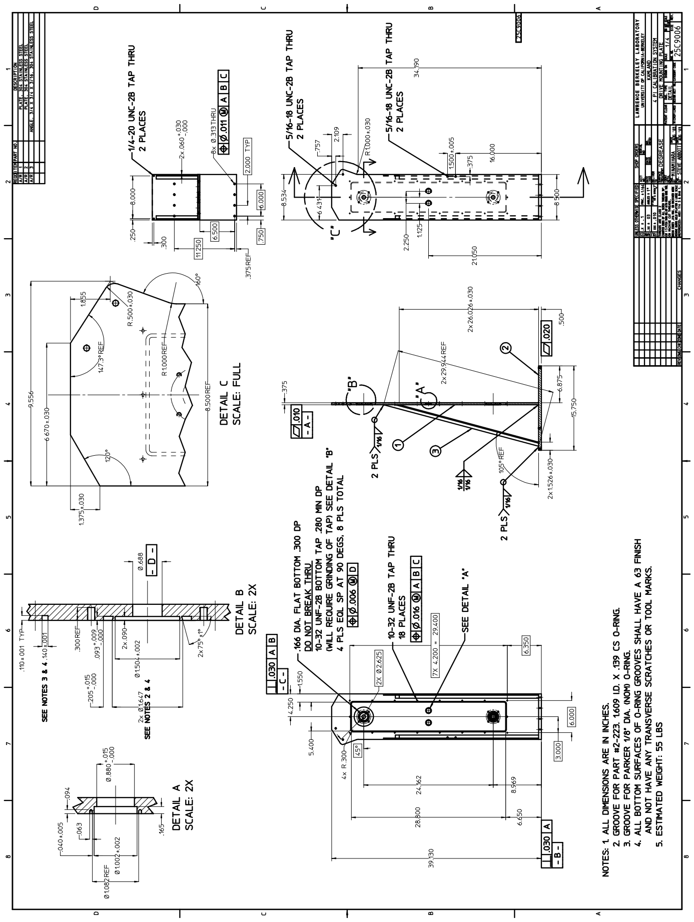


Figure 18: Technical drawing of the mounting plate for the motor winch system.

4.5.1 Installation

The installation will require temporary removal of the side panel of the glovebox, removal of the z-axis system, and replacement of the top plate. More information is given on installation in section ??. Extra stabilization of the glovebox will be installed. This stabilization is provided by a pole secured to the bottom of the crane rail and attached to a rotating bearing on the top plate of the glovebox. This is to provide extra stability of the entire spool and glovebox stack. The primary intention for this extra point of stability is to reduce any motion of the glovebox from user interaction which may be translated into extraneous motions of the pole. The placement and weight of the motors will provide a counterbalance for the present glovebox transfer box. The exact weight and necessary compensations are to be determined. Clearance was provided in the design to accomodate the existing laser cables in the glovebox.

4.6 Motor Controls

A complete servo motor system was purchased from Western Technology Marketing. It consists of three servo motors and motor drivers, two gearboxes, one motion controller, and associated cabling. Manual controls such as a jog button and foot pedal control will be designed and built. Installation and ASCII based programming guides were provided.

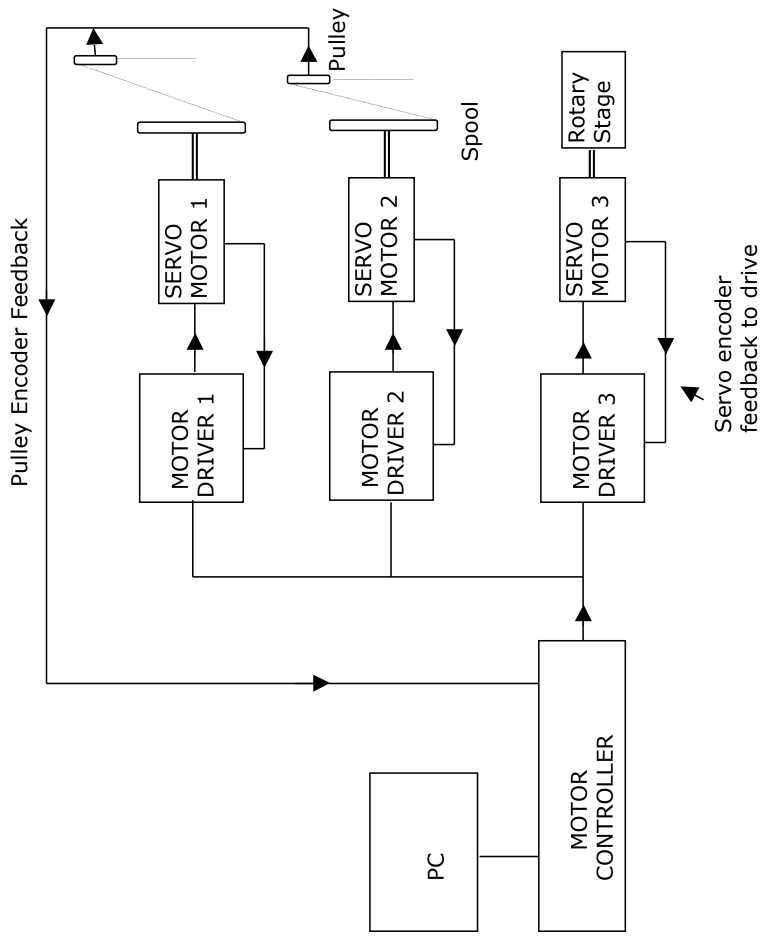


Figure 19: Schematic of motor control system

Two servo motors will be used to operate the cable spools. They will be equipped with worm gear drives to prevent slipping, especially in the event of a power failure. They are brushless DC motors (spark-free) and operate smoothly at slow velocities. The continuous torque is on the order of 7 inch-lbs. Servo motors were chosen due to the motor driver ability to provide constant feedback and adjustments on the supplied voltage, torque, and actual motion relative to the programmed position information. The positions of the cables will be retained by the motor controller in the event of a power failure. A battery back-up system will be utilized to operate the system if needed until power is restored. The system will be programmed with a torque limit. If a given torque is exceeded the driver will stop and an alarm will sound. This has the built in safety feature comparable to the slip clutch on the present z-axis system, which is to cease motion commands if the system motion is obstructed. The motor controller receives feedback directly from servo motor encoders. This allows the operator to monitor the progress of a programmed motion command. It will also receive and compare the readout from the US Digital encoders on the cable pulleys. The controller will be programmed for slow acceleration and deceleration, and for repetition.

The rotary stage will be operated by a servo motor which is also connected to the main motor controller. The phi position will be software controlled (but care needs to be taken to avoid hardware complications outside of the glovebox during this process). The key to detector safety is in the ability to program and operate the two motors within an acceptable region. This can be done with a set of algorithms which define relative position parameters for the two cables.

4.6.1 Programming Motion Control

Programming will be as simple as allowed to ensure safety of the detector.

- Torque limits
- Different parameters for each different radial position. This is based on a modified weight/center of mass.
- Acceleration and deceleration parameters for each start and stop command.
- Position of the pivot block attachment point.

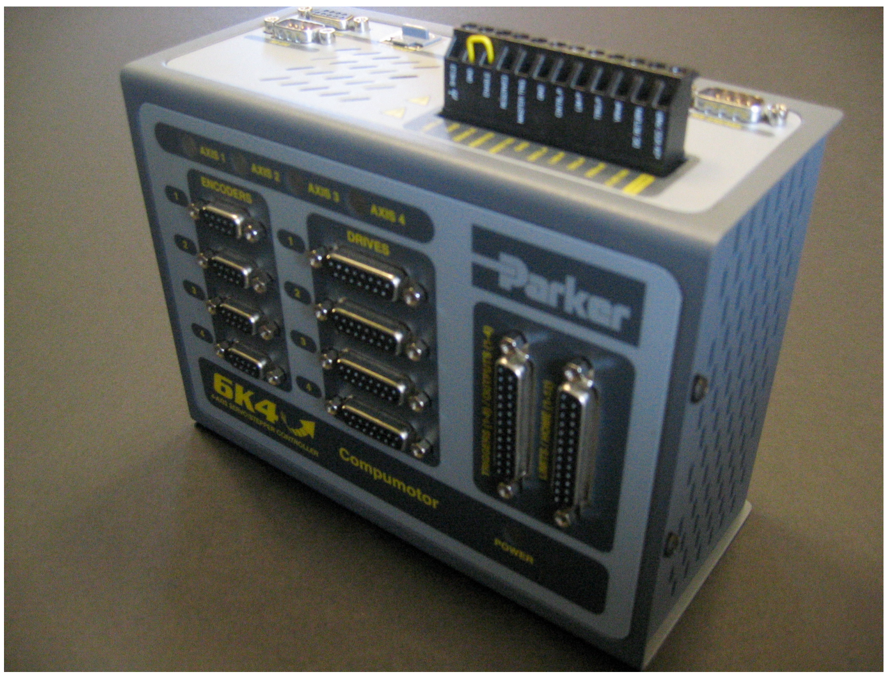


Figure 20: Controller for the motor winch system.

5 Control of the Calibration System

The off-axis calibration pole can be operated in two different modes:

1. Computer-controlled deployment and operation (*standard*)
2. Manual operation of deployment system (*emergency*)

In normal operation the pole is deployed and monitored through a computer-based slow control system. The design and features of this system are outlined below.

5.1 Slow Control System

The control software is charged with two responsibilities: to allow an operator to deploy the calibration source to a chosen position within the detector, and to ensure that the motion never causes any component of the 4pi system to enter the forbidden safety zones defined near the balloon. Ideally, these safety zones would be enforced by a completely redundant interlock system (preferably completely hardware-based) separate from the system used to control the motion. Although the geometry is complex enough that this ideal cannot be completely realized, a number of redundant checks will still be performed.

In a routine deployment, the operator will simply input the coordinates to which the source position should move. The program will then compute a sequence of actions that will place the source at that point, checking at this point, before any motion has begun, that its plan does not compromise the safety zones. It will present the plan to the operator as a table of distances by which the two cables will be raised or lowered. It will also illustrate the proposed trajectory overlaid on a graphical model of the detector geometry. The operator will be able to edit the plan at this point; the program will validate any proposed changes to ensure that they do not lead to a violation of the safety zones.

After the operator and the program have agreed on a motion plan, it will be executed in discrete steps of order 10 cm. Each step will require the explicit approval of the operator. Also, before each step, the program will revalidate that the step will not cause an infringement of the safety zones. Each step will be made with acceleration and deceleration that are slow enough to avoid inducing excessive vibration.

After each step, the encoder values will be read back from the motors and the pulleys and compared for consistency with each other and with the commanded motion. Any discrepancy among the values will be flagged prominently so that the operator can make a decision on the next course of action. At these pauses, the graphical model will be updated to indicate the program's new concept of the current positions of all components of the system.

5.1.1 Software Architecture

It is anticipated that the control software will be written in the Java programming language. It will communicate directly with the Gemini GV drives and the 6K4 controller over RS-232C serial lines, using the JavaComm standard extension. The primary user interface will use the Swing toolkit, and the graphical detector model will use Java3D.

5.2 Manual Operation

The spools and motors can be operated manually for emergency retrieval of the system.

6 Deployment and Operation

This section gives an overview of the deployment and operation of the off-axis calibration system. For a detailed step-by-step description of operation see the deployment protocol in Appendix D.

6.1 Deployment System

Figure 21 shows a 3-dimensional illustration of the 4π deployment system, including glovebox extension and layout, motor-winch system, and calibration pole storage.

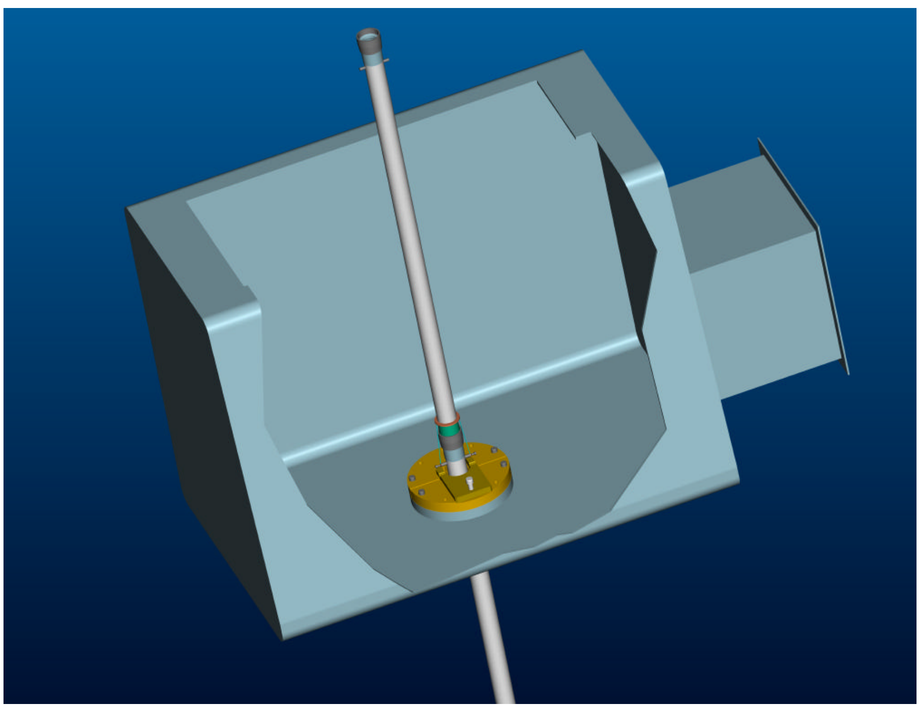


Figure 21: Three-dimensional illustration of the 4π deployment system, including glovebox extension and layout, motor-winch system, and calibration pole storage.

6.2 Deployment Sequence

The off-axis calibration pole will be assembled from individual segments inside the extended glovebox. As the pole is assembled it is lowered into the detector. The control cables are attached to the ends of the calibration pole when appropriate during the assembly procedure.

Once the pole is fully suspended and suspended from the control cables it can be lowered vertically into the detector. The pivot block is attached to the control cables to control the sideways motion of the pole. When the pole reaches the center of the detector it can be rotated from a vertical to a horizontal orientation.

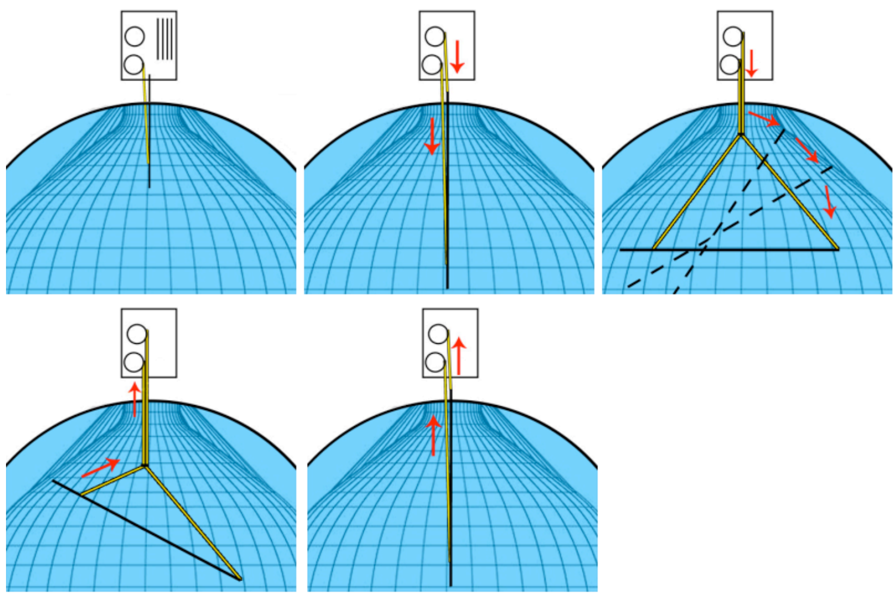


Figure 22: Schematic illustration of the deployment sequence for the calibration pole.

By adjusting the length of the control cables the angular (θ) position of the calibration pole can be adjusted. For safe operation the angular range of the calibration source will be limited to +80/-90 degrees from the horizontal.

The ϕ position of the calibration source is adjusted with the rotary stage. It is preferred to retract the pole in the vertical position until one end is securely in the pinblock. This reduces drag motion on the pole, and the possibility of cable tangling due to the rotation.

For retrieval the calibration pole is turned into a vertical position and then retracted through the 6" glove box opening into the glovebox. The pole is disassembled segment-by-segment inside the glovebox.

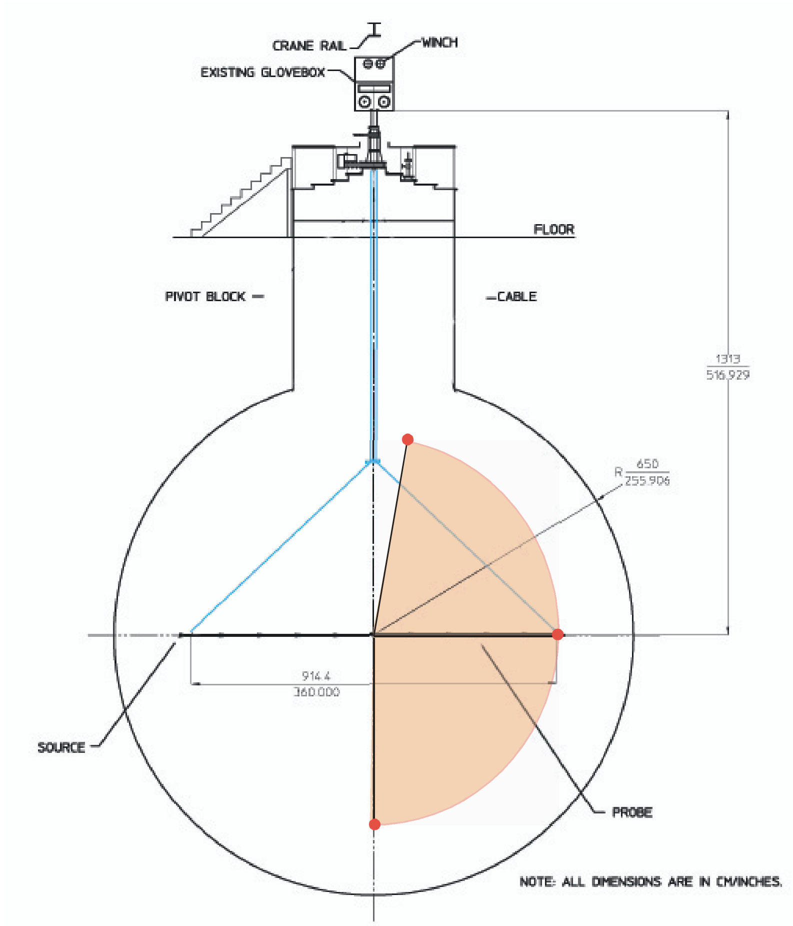


Figure 23: Angular range in θ of the calibration pole.

6.3 Operators

This off-axis calibrations system is designed for use by a single operator but we expect that two operators will be present at all times. The primary operator will perform the assembly of the calibration pole, its deployment, and manipulate it inside the detector. The responsibility of the second calibration expert is to ensure the correct execution of step-by-step procedures and to cross-check the activities of the primary operator. The second calibration expert can also assist the primary operator in emergency situations.

7 Positioning and Position Determination

A combination of methods will be used for position determination of the calibration source.

7.1 Depth Measurement

Hermetically sealed pressure transducers will be incorporated into the pole at one or both cable attachment points. One pressure transducer may also be positioned at the pivot block. The transducers are encased in stainless steel housing and utilize a piezoresistive silicon sensor to obtain an accuracy to about 1cm. It is designed for use in corrosive media, using a 316 stainless steel membrane as an interface between the outer medium and the sensor. It has a built in temperaure compensation adjustment. A circuit to increase the output signal gain has been designed and tested. The information from the transducers will provide the z position of the ends of the pole, and subsequently the angle theta needed to determine the position of the source. See the appendix for specifications, 39.

7.2 Cable Length

Two rotary optical encoders will be used to yield real time information on the lengths of the control cables. Each of the control cables are despooled over guide pulleys as described in **??**. The encoders will be mounted at the ends of the guide pulley shafts. They optically sense the number of turns on each of the pulleys, thereby yielding information on the length of cabling which has been despooled into the detector. The servo motor feedback will verify that this information is correct by doing a real time comparison of the completed number of steps programmed into the controller relative to the number of turns of the guide pulley. (Additionally, this position is again verified by another built in encoder system feedback loop between the servo motor and the driver). The encoders with a digital readout have been purchased and are being implemented into the prototype winch system. Pretensioning of the cables, testing for repeatability of the cable length, and ensuring that there is no slippage on the pulleys are integral parts of the development plan for encoder integration. The encoders are accurate to within 1 cm.

7.3 Pole Length

The length of the pole between the cables provides the information needed to reconstruct the geometry of the system for each source position. Once the positions of the ends of the pole and the lengths of the cables are determined, the length of the pole yields a final verification of the position of the calibration source.

7.3.1 Deflection Measurements

The length of the assembled pole is essentially known, but the actual distance between the ends of the pole will have a small margin of error due to deflection. The table **??** shows a calculated deflection of the pole in air. This will vary slightly as a function of mass and of position (relative to the force of gravity).[1] Initial deflection measurements of the prototype using a laser level were done with a result of 4" over a 288" pole (comparable to the calculated effect). Given the density of oil, this deflection may in the end be negligible, and an accuracy to within a few centimeters may still be easily achievable without these calculated effects.

7.3.2 Location of the center of mass

The geometric center of the pole will change as weight is added to one end. Preliminary testing of the assembled pole in oil will ensure that the calculated center of the pole is accurate, and will yield baseline information for each pole configuration as a function of the change in radial position.

7.3.3 Source endpoint

The distance between the end of the cable and the actual end of the source will be taken into consideration. This will be roughly 24", and will have very minimal deflections. However, it will still be examined, in addition to its slight cantilever effect on the pole deflection. It may be possible to install a pressure transducer all the way to the end of the source side assembly.

[1] It was seen through prototyping that the deflection decreases as the pole is rotated back to the vertical position without deformation. This is true even after the pole has been left hanging horizontally in air for a number of days.

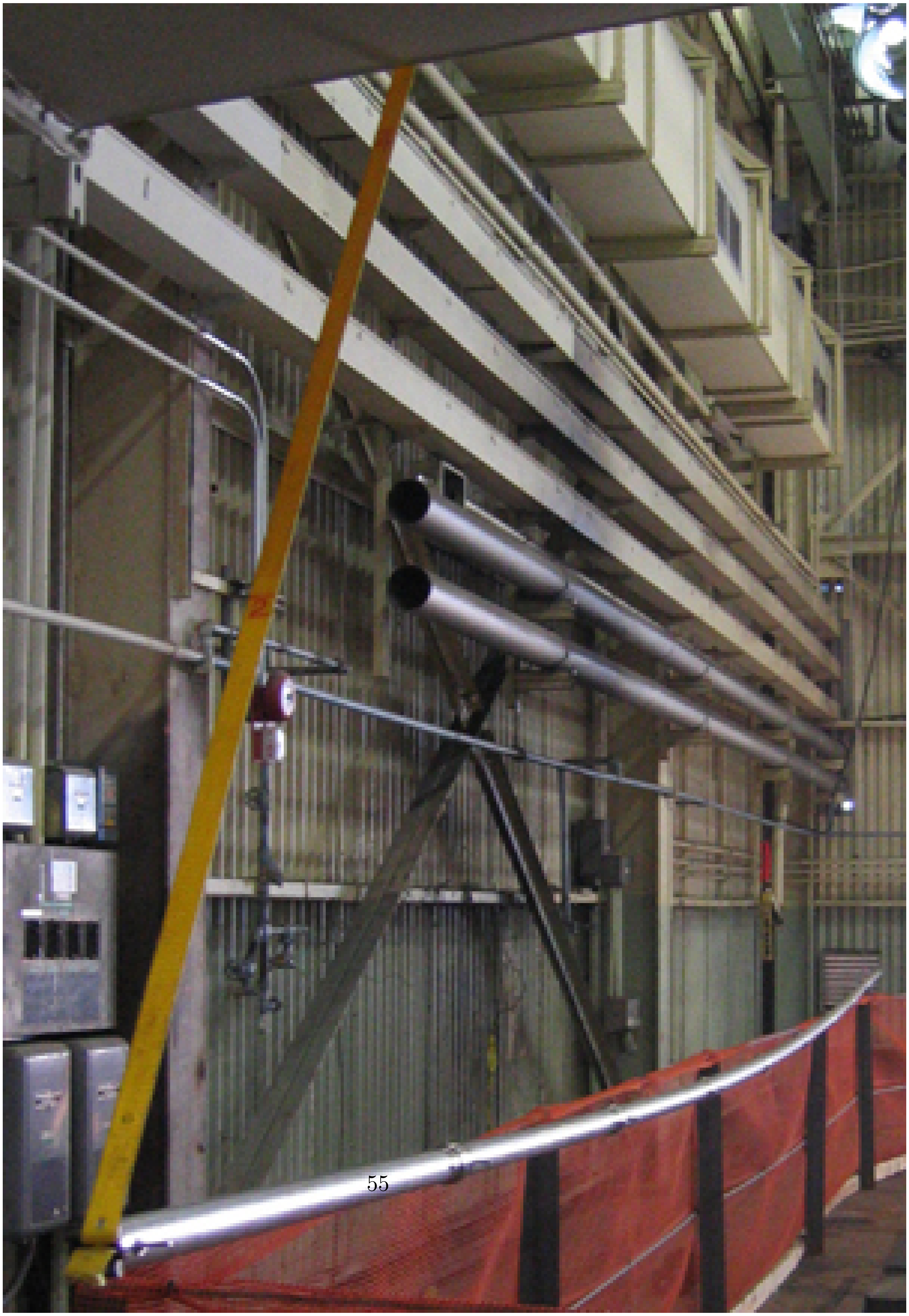


Figure 24: Photograph of the prototype pole in the horizontal position.

7.3.4 Assembly requirements

It was found that the deflection of the pole is also a function of the amount of torque used to assemble the couplings. In the previously mentioned measurement, the couplings were torqued to about 25 ft-lbs. A previous observation with the couplings assembled without a torque wrench yielded a deflection on the order of approximately 8". Changes in deflection as a function of torque will be tested further to find an optimal and repeatable amount of torque.

7.4 Rotary Stage

The position of the rotary stage will give information on the phi position of the pole. The entire glovebox will be rotated using the existing rotary stage on the 6" spool. A servo motor will operate the stage. Modifications of the present system may need to be made to avoid interference with existing electrical and gas connection hardware. The phi position information will be given through the main motor controller.

7.5 LEDs and CCDs

Light emitting diodes (approximately 950nm) will be utilized at the ends of the pole in conjunction with the CCD cameras which are already installed within the perimeter of the detector. The wavelength of the LEDs will be outside the detectable spectrum of the PMTs, within the wavelength sensitivity of the cameras, and at a wavelength which is not absorbed by the scintillator. This will provide visual monitoring of deployment through CCD imaging, as well as an additional off-line position reconstruction. Preliminary tests of reconstruction using an LED source at several points along the z-axis yielded an accuracy of 3cm. If further testing does not provide the accuracy needed by this method for position determination, the LED/CCD system will still be a useful monitoring tool throughout deployment, positioning, and retraction.

8 Data Taking and Analysis

Data taking with the new off-axis calibration system is done in a similar way as calibrations with the z-axis system.

Information on the position of the calibration sources will be obtained from 3 independent systems:

1. Length of control cables as determined online by guide pulley encoders.

2. Depth of pole ends as determined online by the pressure transducers.

3. LED positions as determined by off-line position reconstruction with the CCD cameras.

It is the responsibility of the 4π off-axis calibration team to provide the analysis group with a set of (x,y,z) coordinates for each calibration point as well as a best estimate of the uncertainty on each position coordinate.

During both the commissioning phase as well as the infrequent 4π calibrations we expect that the 4π team on site will focus primarily on the safe operation and deployment of the system. The team will be assisted with an off-site group of analysts who will

- transfer the data (or a subset thereof) from Mozumi to LBNL
- process the data and verify its integrity
- provide feedback on the quality of calibration data to the on-site 4π team

For selected calibration data the turn-around time for the transfer, processing, and analysis of the data will be 24-48 hrs. This will provide a close-to real-time data check.

Besides the obvious interruption of detector operation for the purpose of off-axis calibrations we do not expect a significant additional workload for regular on-site personnel.

9 Prototype

This section shows a collection of photographs of the prototype system currently in use at Berkeley Lab.

Figure 25: Photograph of the prototype deployment system and calibration pole. The prototype system is in operation at Lawrence Berkeley National Laboratory.

Figure 26: Photograph of the prototype deployment system at Lawrence Berkeley National Laboratory.

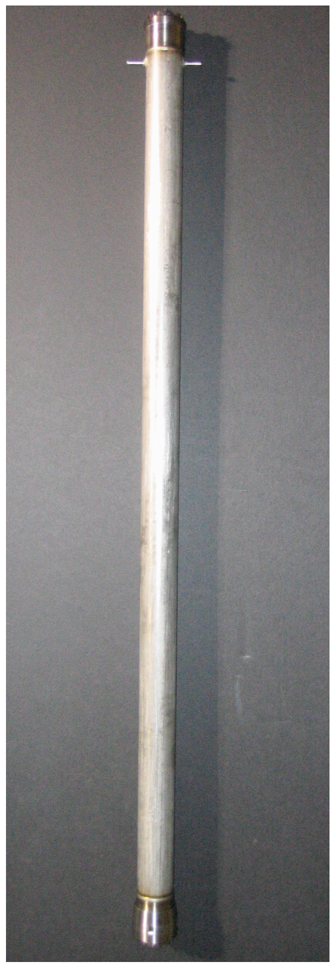


Figure 27: Prototype of calibration pole segment.
Photograph of a calibration pole segment. The prototype only shows one of the two horzontal dowel pins that are used to engage and secure the segment in the pin block.

Figure 28: Photograph of BTC fitting (Bicyle Torque Coupling) connecting individual pole segments.

Figure 29: Photograph of the prototype for the internal calibration pole safety line. The line connects individual pole segments and provides a back up to the BTC.

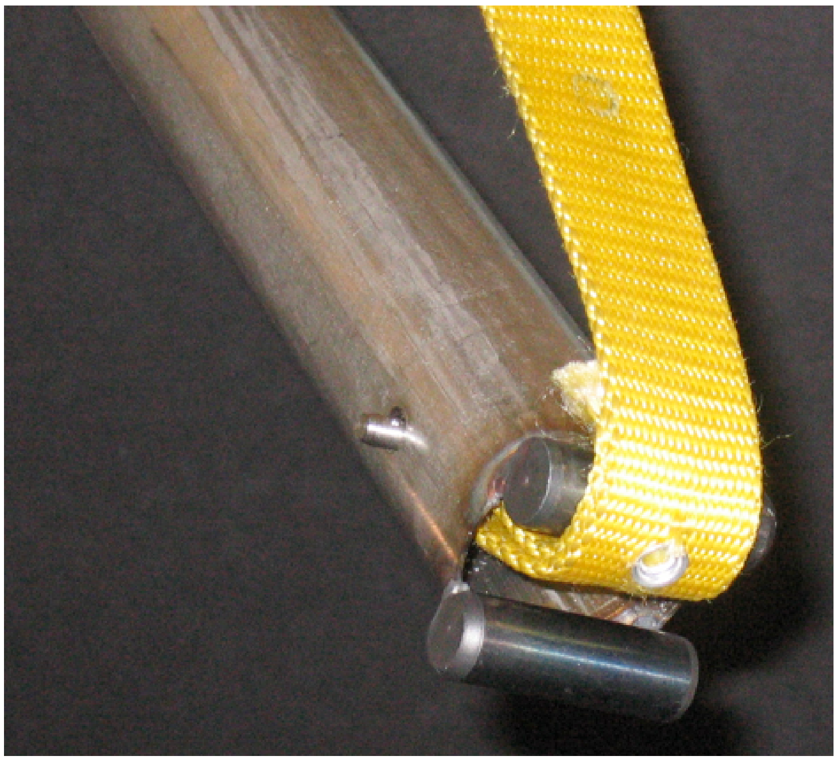


Figure 30: Cable end of the prototype calibration pole. *Note: This is NOT the design for the final calibration pole.* The design of the termination and connection of the real control cable is still under development. It will include electrical terminations as well as load-carrying connections.

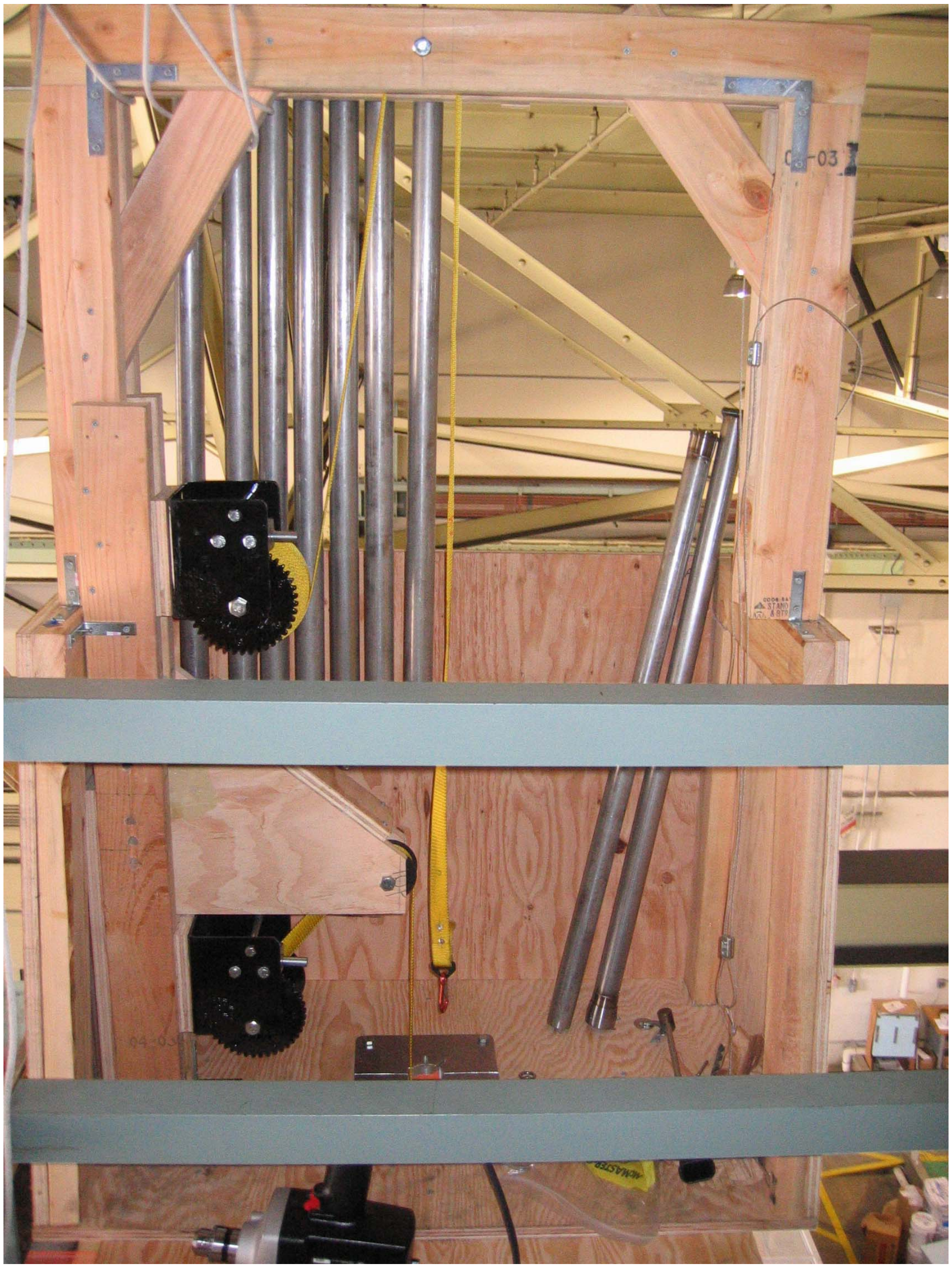


Figure 31: Prototype glove box with the storage rock of the pole segment in the background.

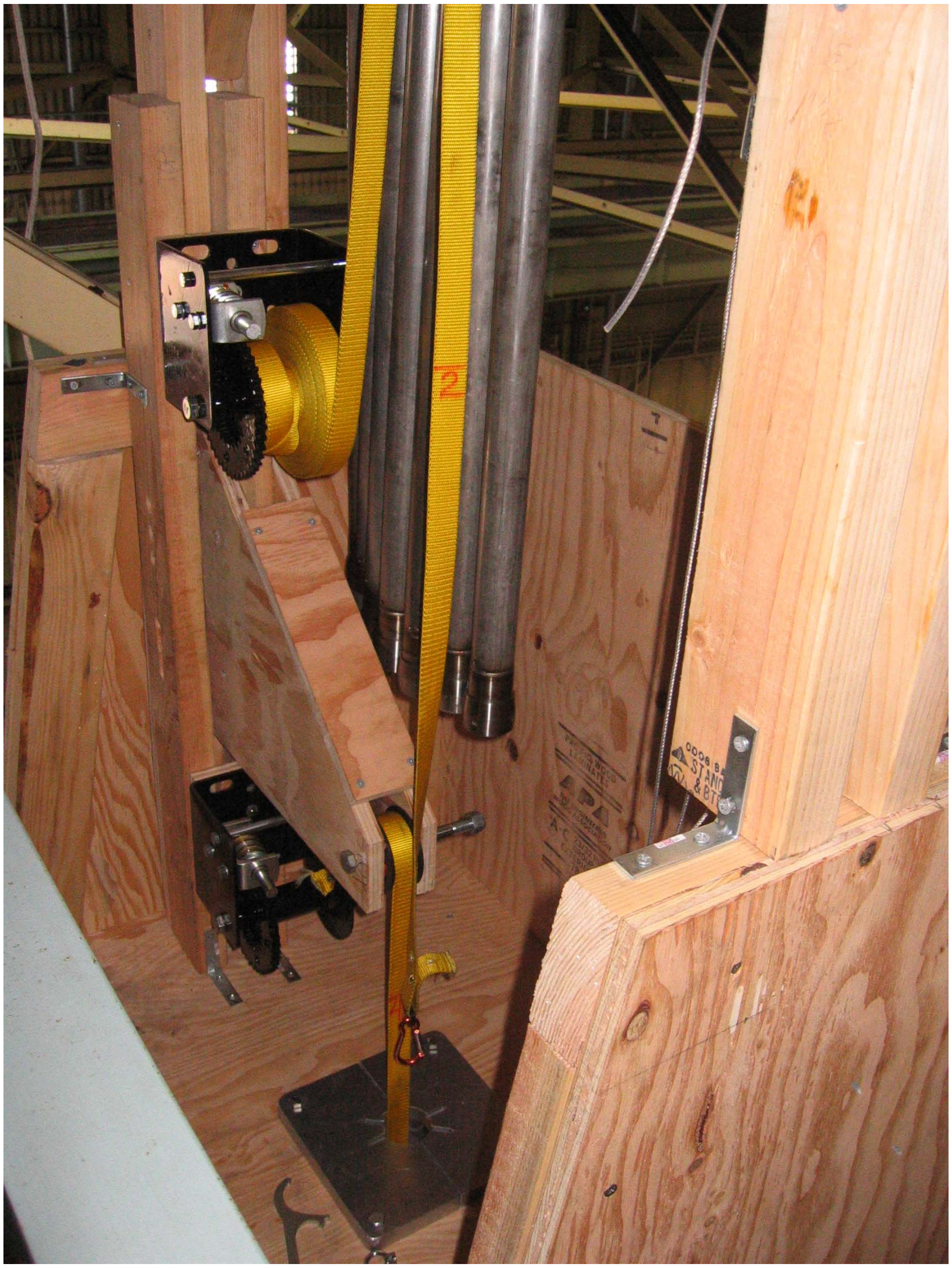


Figure 32: Photograph of the prototype glove box with the motor winch system and the guide pulleys.

10 System, Detector, and Operator Safety

10.1 Design Considerations

1. **Safe Materials:** All materials are compatible with liquid scintillator and satisfy the cleanliness requirements of the detector. The titanium calibration pole is light weight, reduces the risk of handling inside the glovebox, and allows the operator to manually retratct the pole in the event of an emergency.

2. **Redundancy:** The system is designed to provide double safety in all aspects of the design, including assembly, deployment, and monitoring. A simple mistake cannot result in damage to the system, the detector, or the operator.

3. **Fail-Safe Design:** The system is designed for fail safety. For example, worm gear drives on the servo motors prevent the system from backdriving or despooling when the motors are inactive.

10.2 Cleanliness of Calibration System

1. All materials are tested and shown not to contaminate the detector prior to deployment.

2. All materials will be adequately cleaned prior to insertion into the glovebox.

3. Care will be taken to keep the existing glovebox and components clean during installation.

4. All tube segments will be thoroughly cleaned and purged with nitrogen prior to installation.

5. Pole segments are designed and fabricated to eliminate air and residual contamination being trapped during deployment. Holes in the pole segments as well as slow deployment minimize the effect of air bubbles.

10.3 Balloon Safety

1. The system is designed to probe the entire fiducial volume of the detector with a safety distance of ≥ 0.8 m to the balloon.

2. Throughout all prototype testing we have seen little to no swinging of the pole in the horizontal direction. The swinging motion we have seen has been less than 5 cm and was a direct result of oscillations caused by the deployment mechanism (i.e., the cables being spooled by hand in the first tests, and a burr on the worm gear of one of the present prototype winches). Repetitive testing has proven horizontal stability of the pole and its subsequent design.

3. The above results are contingent upon the tempered motion and fluidity of the operating system. The acceleration and deceleration features of the motor controller will provide careful starting and stopping of the system. Operation at low speeds will eliminate any unnecessary motions. Motion velocity and acceleration will be programmed to cause the least disruption possible to the detector.

10.4 Detector Safety During Deployment

We don't anticipate any problems with the flexible membrane at the 24" opening or other detector components. All components except for the pivot block (and possible AmBe source?) will be less than 5 cm in width. the pivot block will be significantly tapered to easily pass through the 6" opening in the membrane.

10.5 In-Situ Testing of Calibration System

In addition to the prototype testing off-site and possible water testing, the calibration system can be tested *in-situ* with a calibration pole of reduced length. The functionality of the entire system can be tested in the KamLAND detector with a pole length of 2-3 m. Such a system would not endanger the inner detector. Subsequently, the pole length can be gradually increased until there is sufficient confidence that calibration at a radius of $R = 5.5\ m$ would not endanger the balloon.

10.6 Operator Safety

Besides the use of calibration sources we anticipate no hazards for the operator of this calibration system. Care must be taken by the gloved operator in the top of the glovebox addition to not interfere with the cable motion over the guide pulleys. This design will be tested further, but poses little hazard for the operator, as this is a friction driven pulley.

10.7 Discussion of Possible Failure Modes

This section discusses the possible failure modes of the system and the techniques that are used to mitigate the resulting risks. Emergency procedures for a safe recovery of the calibration source are outlined.

10.7.1 Power Failure

The hardware and control systems for this calibration system will be backed up by a separate UPS unit. In the event of a power failure and subsequent UPS failure, the calibration pole and source can be retrieved manually. The motor winch system is designed for manual operation. A worm gear between the servo motors and the winches prevents back drive of the motor winch system. In the event of a complete power loss, no position monitoring devices will be available.

10.7.2 Crash of Control Computer

As in the event of a complete power loss, emergency retrieval of the calibration source and pole will always be possible. No motion of the calibration system will occur if the power fails. The stillness will remain once the power returns. In this event, it is best to wait for power to be restored, and then retract the pole using current pressure transducer information and the assurance of the LED/CCD system.

10.7.3 Failure of A Motor Winch

The calibration pole is controlled by two motor winches. In the case of failure of one winch, the other winch system can be used for an emergency retrieval of the calibration pole and source. If the weight end motor fails, the hoist retrieval system has been designed to allow re-routing of the bottom cable to retract the pole source side first.

10.7.4 Failure of Encoder Pulleys

The failure of encoder pulleys will result in the loss of information on the length of the control cables. This information is not required for the safe retrieval of the calibration pole.

10.7.5 Failure of BTC Coupling of Pole Segments

If a BTC coupling fails during deployment due to incorrect assembly, an internal shock cord will assure that the individual pole segments stay connected. The reading of the pressure transducers and the LED imaging will indicate the pole failure. In such an event, the remains of the calibration pole can be retracted.

11 On-Site System Integration, Installation, and Commissioning

The following is a general overview of the necessary work in preparation for the installation, commissioning, and deployment of the off-axis calibration system.

Preparations for the deployment of the off-axis calibration system can be done without interfering with routine z-axis calibrations and general detector operation. We suggest that this work takes place in parallel with the completion and off-site testing of the deployment hardware at Berkeley. This work is necessary for the efficient installation and commissioning of the hardware.

11.1 Preparation

We expect that the preparation as outlined below can start as early as February 2004.

1. **Receiving and Storage Area:** Identify receiving and temporary storage area for deployment hardware.

2. **Clean Area:** Establish clean area for preparation, assembly, and final testing of the system. The system will be shipped clean and double or triple wrapped. Once it has been received and unpacked on site it will be inspected and tested under clean conditions in the dome area before installation. A simple, final alcohol cleaning can be performed prior to installation.

3. **Storage Area:** Identify storage area for off-axis calibration system at which it can be safely and cleanly stored for 6+ months when the hardware is not in use.

4. **Modifications to Calibration Tent:** Modifications need to be made to the present glovebox tent to increase the height, and to secure the top of the modified glovebox to the crane rail for added stability.

5. **Motor for Rotary Stage:** Replacement of the gasket on the present rotary stage, and installation of its servo motor. This involves cleaning, resealing, closing of the six inch gate valve, and purging with N2.

6. **Aligment of Glovebox Extension:** Removal of the glovebox top plate, test template of glovebox addition holes to verify alignment.
7. **Data, Communication, Power:** Install data, communication, and power lines for off-axis calibration control system.
8. **CCD Camera Readout:** Installation of hardware or systems needed for the readout of the CCD cameras.
9. **Receiving the Deployment Hardware On-site:** Transport into the mine, unpacking, and assembly in clean conditions.
10. **Final On-Site Hardware Test:** Test of the clean, assembled hardware in dome area includes basic functionality of the motors, pressure transducers, and LEDs.

11.2 Installation

1. **Removal of z-axis System:** Removal of side panel, Removal and storage of z-axis system.
2. **Installation of Motor Mounting Plate:** Installion of motor mounting plate assembly. Connect electrical wiring through KF flanges.
3. **Installation of Glovebox Extension:** Installation of glovebox addition. Installation of tube segments. Connection of nitrogen ports. Cleaning, preliminary testing, and reinstallation of side panel.
4. **Leak Check and Purge:** Leak checking of seals on all panels and gloveports. The system will be adequately cleaned and flushed with nitrogen prior to installation, and purged again once the system is in place.
5. **Light Seal Check:** Check of light seal using neck PMTs.

11.3 Commissioning

A detailed commissioning plan is being developed. The idea is to have a phased commissioning plan that tests and verifies *in situ* the functionality of the system and provides milestones for the evaluation of the system.

1. **Z-Axis Calibration with New Deployment Hardware:** This will test the basic functionality of the system and allow a cross-comparison with previous z-axis calibrations. In this test the calibration pole will not be deployed. Only one of the control cables is used to lower the source into the detector. The functionality of the slow controls, the pressure transducers, and the deployment system can be tested in situ without any danger to the balloon.

2. **Commissioning of Calibration System with CCD Camera Monitors:** As a final test of the functionality of the system we propose to run the system in the detector under monitoring with the CCD camera. This allows the operator to visually verify the correct operation of the system. The PMT high voltage would be turned off during that time. It also exercises the on- and off-line position readout.

3. **Removal of Thermometers:** Prior to the deployment of the calibration the thermometers inside the detector need to be removed.

4. **Phased Deployment of Off-Axis Calibration Pole:** A detailed proposal is being developed for the sequence of deployment of the off-axis calibration pole. The system will first be run only in the z-axis mode. We can then add the minimum number of off-axis pole segments and calibrate the detector off-axis without endangering the balloon. As we gain confidence in the operation of the system and the operators more pole segments can be added until the full-length calibration pole is deployed. In the *symmetric* deployment mode, even the longest pole of ~ 8 m will extend only ~ 4 m off the central axis. As a final step in the commissioning process we add the weighted end to the pole which allows the *asymmetric* calibration.

11.4 Full Deployment and Off-Axis Calibration

Once the system has been successfully commissioned it can be used for the off-axis calibration of the detector. A detailed calibration plan specifying the sequence of calibrations, the number of calibration points, and the duration of calibration is being developed.

12 Schedule and Milestones

The anticipated design and fabrication schedule for the off-axis calibration system is shown in Figure 33.

Some of the major milestones are:

- **Completion of design of all hardware:** December 30, 2003
- **Completion of fabrication of all hardware:** January 26, 2004

We expect to be able to start some on-site preparations by February 2004. The detailed on-ste installation and commissioning plan for this system will be coordinated with the KamLAND on-site coordinators. The installation and commissioning activities are discussed in Section **??**

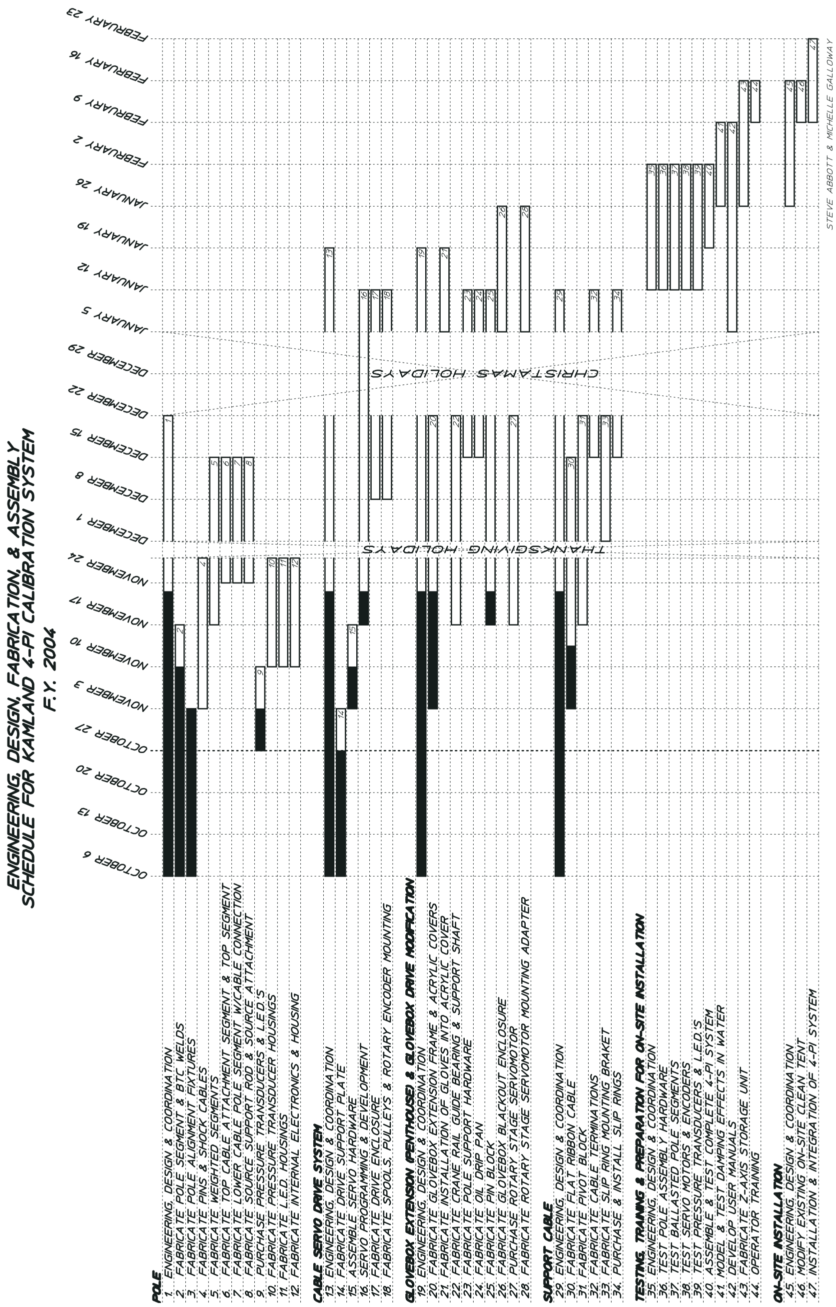


Figure 33: Schedule for completing the design and fabrication of the off-axis calibration system.

References

[1] ...

A Glossary

GLOVEBOX EXTENSION – An extension to the extisting glovebox will accomodate the segments of the calibration pole as well as the deployment system for the off-axis calibration pole, including motor winch system, control pulleys, and pinblock.

CALIBRATION POLE – Segmented pole to be deployed in the inner detector volume. A calibrations source is attached to one end of the calibration pole. The pole is suspended by two flexible control straps. It consists of up to 8 segments with an overall length of approximately 24ft / 8 meters.

POLE SEGMENT – Titanium tube (3-ft long, 1.5" diameter) with BTC couplings on both ends.

STORAGE RACK – Metal plate design for storing the pole segments inside the glovebox extension.

END SEGMENT – Segment at end of calibration pole. It contains the counter weight for an asymmetric deployment of the calibration pole. Also referred to as the "weighted end".

COUNTER WEIGHT – Tungsten and/or stainless steel rod inside a sealed titanium pole segment shifts the center of mass of the off-axis calibration pole.

BICYCLE TORQUE COUPLING – Coupling mechanism to connect segments of the calibration pole, often referred to as "BTC".

INTERNAL SAFETY CORD – Internal safety line that connects adjacent pole segments and serves as a backup line for the BTC couplings.

SOURCE HOLDER – The source holder attaches to the end of the calibration pole. It is a BTC segment with an attachment rod which is identical in operation and specifications as the z-axis source attachment rod.

CONTROL CABLE – Webbing or cable with a strength member which suspends the calibration pole and is used to control the motion of the calibration pole. It may be round or flat webbing, and may or may nor contain electrical conductors.

MOTOR WINCH SYSTEM – Sealed servo motor winch system inside the glovebox to operate the control cables of the calibration pole. The motor winch system consists of two independent motors which drive two spools containing the control cables.

PULLEY ENCODERS – Each of the cables is despooled over a guide pulley. Each guide pulley has an optical rotary encoder coupled to its shaft. The pulley encoders provide real-time feedback on the length of the control cables as they are paid out into the detector.

PIN BLOCK – The pin block covers the 6-inch opening in the base of the glove box. It supports the segments as they are being assembled.
PIVOT BLOCK – The pivot block is attached to one control cable and guides the other control cable. It ensures that both control cables run parallel and vertical to the pivot point at which they fan out to either end of the calibration pole. The calibration pole and the pivot point form a triangle.
DOWEL PINS – Horizontal pins through the pole prevent the pole segment from falling through the pinbock during assembly and deployment. They are also used to fix the pole for torquing the BTC coupling, and for holding the internal safety cords.

PRESSURE TRANSDUCERS – Pressure sensors attached to the calibration pole to measure the pressure (depth) of liquid scintillator in the inner detector. The accuracy is about 1 cm.

POSITION LEDs – Infared calibration LEDs attached to the calibration pole that provide calibration points for possible off-line position reconstruction and deployment monitoring.

B Materials and Materials Compatibility

Note: This section is out-of-date after recent design changes. Please contact Michelle Galloway or Karsten Heeger for up-to-date information.

The following is a list of all materials used in the off-axis calibration system.

Material	Use	Approved	Required	Application
Acrylic	D, Gbox	Yes		Housing for electronics, Glovebox panels
Anodized Aluminum	Gbox	Yes		Misc Glovebox hardware
Delrin	D, Gbox		S,O	Pulleys, possibly pivot
Encased Electronics	Detector		R	Sealed circuitry for transducers, etc.
Gold	Detector	Yes	?	Pins of hermetic connectors
Kalrez	D, Gbox		S, O	Back-up for viton seals
Kevlar	Detector	Yes	S, O, R	string, webbing, cord for cabling
Mineral Oil	Detector	Yes		Lubricant for coupling threads
Nylon	D, Gbox	Yes	S, O	Material in hermetic connectors, wrench
PolyU 421 Primer	Detector		S,O	Primer for cables, polyurethane based
Polyurethane	Detector	S	O, R	cable coating
PRC 1592	Detector		S,O	Sealant for cables, polyurethane based
PTFE, teflon	Detector	S	O, R	possible cable coating, pivot hardware
PVC	Detector	?	S, O, R	possible cable coating
Silicon	Detector		S, O, R	P Transducer, made for corrosive environments
Stainless Steel 304	D, Gbox	Yes	R	weights, connectors, cords, wrench, frame
Stainless Steel 316	Detector	Yes	R	Pressure transducer housing
Titanium	Detector		S, O, R	pins, misc hardware
Titanium, 3Al 2.5V	Detector	R	S,O	tubing, couplings
Viton	D, Gbox	Yes		Seal, purchased from DuPont qualfied vendor

S - Soak Test
O - Optical Transmission Test
R - Radioassay

Figure 34: Table of materials used in the off-axis calibration and deployment system.

Note: A detailed plan for testing the materials compatibility and cleanliness of all components of the off-axis calibration system is under development. Please contact Michelle Galloway or Karsten Heeger for more details.

C Radioassay Results of Titanium Tubing and BTC Coupling

Radioassay Results from Titanium Tube and Coupling Samples

All three samples were counted together on the largest detector (MERLIN) at the LBNL Facility. The two samples of round stock were positioned on the flat face of the detector endcap, while the pieces of split tube (12 pc) were arranged around the cylindrical sides of the endcap.

Sample weights:	Total	=	1074 grams
	Rnd #HC12362	=	254 grams
	Rnd #8607528	=	324 grams
	Tube pieces	=	496 grams

Data File: 17378
Count time = 176601 sec

U(early)	=	19.(1) ppb
U(late)	=	0.5(4) ppb
Th(early)	=	ND
Th(late)	=	8.(1) ppb
K	=	2.7(6) ppm

U(early) signifies the equivalent U-content of nuclides earlier in the decay chain than Ra-226. U(late) signifies the equivalent U-content of nuclides from Ra-226 through the end of the chain.

Th(early) signifies the equivalent Th-content of nuclides earlier in the decay chain than Th-228, with the following qualifier. If refining of the metal occurred within about 6 months of the measurement, the late members would not have grown in to a detectable level. Th(late) signifies the equivalent Th-content of nuclides from Th-228 through the end of the chain.

ND signifies no gamma-rays from these nuclides could be detected. Numbers in parentheses() indicate the magnitude of one-sigma uncertainty in the listed values. The one-sigma numbers are derived from counting statistics alone.

Figure 35: Radioassay results of titanium tubing and BTC coupling.

D Deployment Protocol

D.1 Initial Conditions

1. All tubes are hanging on the storage rack in the glovebox.
2. Both the 6" and the 16" gate valves are closed.
3. The calibration sources (attached to the specialized BTC segments) are in the glovebox, and the glovebox and transfer box have been adequately sealed and purged.
4. Both control cables are fully retracted inside the glovebox, just below their respective guide pulleys.
5. The pin block is firmly attached to the conflat flange on the bottom of the glovebox.
6. The hoist segment and all of the weighted segments are placed in their respective storage racks inside the glovebox.

D.2 Preparations for Assembly

1. The hoist segment is placed into the pinblock. (This attachment is a male BTC coupling with a hook welded below it). This segment has two pins. The bottom pin (pin closer to hook) is placed into the pass through slot on the pinblock. It then needs to be rotated 30deg CCW to be lowered. This action allows the top pin to rest securely in the torque slot of the pinblock.
2. The top motor driven cable (from now on referred to as the hoist cable for assembly and disassembly operations) is lowered to just above the pinblock. This cable end is permanently attached to a short segment with a female BTC on the other end.
3. The operator then attaches the internal cord. This is done by clasping the snap hook or carabiner hanging from the cable end attachment onto the eye hook inside the hoist attachment segment.
4. The hoist is lowered as the operator aligns the castellations of the two segments. The visual fiducial marks on the two segments are simultaneously aligned.

5. With the castellations aligned and pressed firmly together, the operator engages the threads of the cable segment coupling onto the threads of the hoist segment coupling and hand tightens the coupling.

6. The top cable is then retracted so that the hook end is just below the top pulley in the glovebox. The pole assembly can begin.

D.3 Assembly of First (Source) Segment

1. The prepared source segment is accessible inside the glovebox. The source BTC connection is double checked prior to installation.

2. OPENING OF 6 GATE VALVE. This is a manual operation which takes place on the calibration deck. A handle directly attached to the gate valve is turned CCW until fully open.

3. A longer internal cord, tether, or possibly electrical cable is first attached between the source segment and the next segment in the assembly, which is still hanging in the glovebox rack.

4. The first segment with the source attached is manually placed into the pin block, source end first. Great care is taken to insert the tube vertically, so as to not hit the source against anything in or along the spool. It is placed so that the lower pin is first rotated CW to pass through the pinblock. A step built into the pinblock will prevent further lowering of the segment.

5. Still holding the source segment, the operator rotates the segment 30 degrees CCW. This will naturally lower the upper pin of the segment into the torque slot of the pinblock.

6. Once the segment is secure, the operator can begin to attach the next segment.

D.4 Attachment of Second Segment

1. The operator manually holds the bottom of the second (or next) segment. The segment is lifted out of the rack. The operator (with possible manual assist from upper gloveports) places the

Figure 36: Photograph of the prototype for the internal calibration pole safety line.

segment onto the hoist, so that the eye opening of the internal cord inside the tube segment fits onto the hoist hook.

2. The short internal cord is connected between the two segments. At this time internal or possibly external electrical connectors on each segment will also be securely attached.

3. The hoist is lowered while aligning the segments until the teeth of the couplings are engaged.

4. The operator first hand tightens the couplings. The operator then uses the supplied, tethered torque wrench to secure the coupling to approximately 25 ft-lbs.

5. Once the coupling is secured, the hoist is raised slightly to lift the lower segment pin out of the torque slot.

6. OPENING OF 16" GATE VALVE. This is done by an operator on the lower deck of the dome area. At this time the detector high voltage needs to be turned off.

7. The operator rotates the assembly to approximately 30 degrees CW to allow the pin to pass through the open slot of the pinblock.

8. The hoist is lowered as the operator guides the top pin of the first segment through the pin block. Once the pin passes through, the operator can manually release the twist on the assembly. The second segment is guided to pass the lower pin through the pinblock (rotation, lowering, and counter rotation) in order to secure the upper pin into the torque slot of the pinblock.

9. At this time the longer safety cord between the second and third segments is attached.

10. The operator disengages the hoist from the segments internal cord and raises it to just below the pulley.

D.5 Assembly of Third Segment (Segment with Cable Attachment):

1. The third segment is lifted and placed onto the hoist hook.

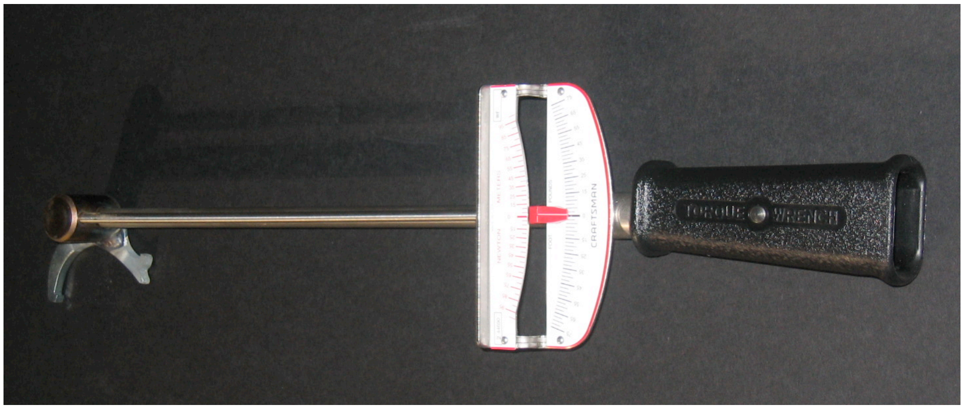


Figure 37: Photograph of the customized torque wrench.

2. The shorter internal cord is connected. Electrical connections are also made between the second and third segments.
3. The orientation of the castellations and the visual markings are aligned as the segment is lowered.
4. With the castellations aligned, the operator manually hand tightens the coupling.
5. The final tightening adjustment is made with the torque wrench.
6. Once the coupling between the second and third segments are secure, the operator lowers the second (lower) cable to just above the pinblock.
7. The operator then attaches the lower cable to the designated attachment point on the pole. This will consist of both a mechanical attachment (tbd) and the attachment of an electrical connector to a feedthrough in the segment.
8. At this time, electrical power to the lower cable can be activated and verified (LEDs work, pressure transducer gives logical readout).
9. The hoist is lifted slightly to release the pin from the torque slot.

10. The pole is rotated 30 degrees clockwise, lowered slightly, released from rotation by the operator, and both cables are lowered until the lower pin of segment 3 reaches the pinblock.
11. The operator rotates the segment, lowers both cables slightly, then releases rotation.
12. Both cables are lowered until the top pin of segment 3 rests securely in the torque slot of the pinblock. From this point on, the upper and lower cable will be lowered simultaneously when an entire segment length is being deployed.
13. Detach the hook and raise the hoist cable to position zero.

D.6 Assembly of Segments No. 4 - 8

1. Raise the bottom of the next segment out of the rack and place onto the hoist hook.
2. Connect the internal cord between the upper and lower tubes.
3. Lower the hoist cable to align the segments and fit the castellations.
4. Tighten the couplings together and secure with the torque wrench.
5. Lift the hoist cable to release the pin from the torque slot.
6. Rotate the assembly (30 degrees clockwise).
7. Lower both upper and lower cables to allow the pin to pass through the pinblock.
8. Release the rotation of the segmented assembly.
9. Lower both cables simultaneously until the lower pin of the upper segment is just above the pinblock (about 76cm/30").
10. Rotate the segment 30 degrees CW and lower until the lower pin of the segment passes through the pinblock.
11. Release the rotation and continue to lower both cables until the top pin rests securely in the torque slot of the pinblock.

12. Detach the hook and fully retract the cable to the bottom of the guide pulley.
13. Repeat all of the above steps until the top pin of the final segment is seated in the pinblock. This procedure is the same for all weighted segments, as well.

D.7 Assembly of End Segment

1. The top pin of the last segment is seated securely in the torque slot of the pinblock. The operator detaches the hoist hook attachment from the eye opening of the last segment.
2. The operator disengages the hook attachment from the end of the cable segment by decoupling the BTC and disengaging the internal cord. It is then stored in its appropriate place inside the glovebox.
3. Connect the internal cord between the last segment and the cable end segment. Electrical connectors inside each of the segments will also be connected at this time. An initial check of the electrical connections can be made at this time (example: verifying that the LED functions and the pressure transducer yields a logical output signal).
4. Align the segments while lowering the hoist attachment to fit the castellations together.
5. Secure the coupling and tighten with the torque wrench.
6. Raise the hoist hook slightly to rotate the assembly.
7. Rotate the assembly to allow the pin to pass through while lowering both cables until the markings on the cable which indicate the appropriate attachment point for the pivot block are in view.

D.7.1 Attachment of the pivot block:

1. Lower both cables simultaneously until the markings for the pivot block attachment are above the pinblock.
2. The pivot block is attached at the appropriate place by sliding the cables into place and securing the side plate of the pivot block.

3. The cable on the fixed side of the pivot block needs to be securely clamped at this time. The operator should check and double check the security of this attachment.

4. If a pressure transducer is being utilized on the pivot block, the two conductive pins should be attached at this time, and the connection verified and activated.

5. Once the pivot is secured, the operator slides the spring loaded pin rest on the pinblock and lowers both cables simultaneously. Once the pivot has passed through the pinblock, the slide can be released.

D.8 Cable Position Calibration

1. During the lowering of the pole, the LEDs mounted on the assembly and the detector CCD cameras can be turned on to allow visual monitoring of the pole during deployment.

2. The operator tells the controller through software) the number of segments being deployed, and the mass of the weighted segment which is attached at the end. The controller will then know the center of mass of the pole based on pre-calculated and preprogrammed information.

3. The pole is now lowered (both cables simultaneously) until the center of mass of the pole is at the center of the detector. This position will be determined by the (precalibrated) readout of the pressure transducers on each end of the pole. It can also be visually verified by the position of the LEDs on the pole relative to the fixed CCD camera displays.

4. Once the center is in place, the operator will need to slightly raise the lower cable until a visual fiducial on this cable is in alignment with a specified point on the inside of the glovebox (possibly on the guide pulley support bracket). Now both cables will be under the tension required to prevent the cable from slipping on the guide pulley. Cable tension provides needed accuracy for the encoder readings. (It may be required that a permanent 2.2kg/1lb mass is always attached to the bottom of this second cable-tbd)

5. The operator now needs to zero out the positions of the cables on the motor controller and the pulley encoders. First the operator adjusts each cable position to align a visual mark on each of the cables to the visual fiducial point inside the glovebox. (For the lower cable, this can be the same mark as the previous step to provide tension) Once the cables are moved to be in alignment with this point a "start" command can be given to the controller which relates to a prerecorded position for each of the cables. The pulley encoders can now also be set to a "start" position.

6. The light cover can now be placed over the glovebox. The cameras and LEDs can be turned off. (Initially, a PMT in the neck of the detector can be turned on to verify darkness requirements). The PMT high voltage can be turned on.

D.9 Calibration by changing θ Position

1. Once the start positions of the pole are verified, the cables can be adjusted in length to place the source at different theta positions.

2. Once the source is stable (oscillations are sufficiently dampened), the calibration run can begin for the desired length of time.

3. Different theta positions can be preprogrammed into the motor controller, or set increments can be preprogrammed. Incremental motion is the safest method for calibration. The number of positions required within theta need to be determined by the calibration group (soon).

4. The first set of calibration data can be obtained for different theta positions. This set will have the same phi position and radial position, and the same calibration source.

D.10 Calibration by Changing ϕ Position

1. Once the first set of data points in theta for a given phi position is obtained, the glovebox can be rotated to obtain different source positions in phi. The safest method for phi rotation is to retract the pole assembly until the first segment is seated securely in the pinblock. This will avoid unnecessary damping and potential tangling of the cables.

2. At the end of the theta calibration, the cables will be moved back to the "start" position. This motion will be determined and run by the preset program, to avoid interference in the "excluded" region.
3. PMT high voltage will be turned off, and the cameras and LEDs turned on. The light cover can also be removed.
4. Once at the start position, the weighted end of the pole can be raised slightly until the lower cable is slack.
5. Both cables can be raised simultaneously until the pivot block is near the top of the spool stack. This may be determined by LED position, encoder readout, and possibly the cable fiducial.
6. The operator pulls back on the sliding plate on the pinblock as both cables are raised. Once the pivot block passes through, the slide plate can be released.
7. The operator detaches the pivot block .
8. Both cables are again raised simultaneously until the top pin of the weighted end segment is near the top of the spool stack.
9. The operator then pulls back on the sliding pin plate and raises both cables until the top pin of the weighted segment is above the pinblock.
10. The sliding pinplate is released and the cable lengths adjusted until the top pin of the weighted segment is securely placed into the torque slot of the pinblock. The assembly is now ready for phi rotation.
11. The rotary stage is activated by a servo motor. The change in phi position will be given to the controller through the programming software. Care must be taken during rotation to ensure that all of the hardware does not obstruct or is not damaged by the rotating glovebox.
12. Once the glovebox is in the next phi position, the pole can be deployed following the above procedure for attaching the pivot block.

13. The operator then follows the above procedure for Cable Position Calibration, then the next set of theta position data can be acquired.

D.11 Calibration by Changing Radial Position

1. Additional sets of calibration data can be acquired at different radial distances from the center of the detector. This can be done either after one set of theta positions and before rotation, or after all theta and phi position data is obtained, then repeated with a different radial distance. This requires retraction of the first two segments of the pole into the glovebox.

2. At the end of the theta calibration, the cables will be moved back to the "start" position. This motion will be determined and run by the preset program, to avoid interference in the "excluded" region.

3. PMT high voltage will be turned off, and the cameras and LEDs turned on. The light cover can also be removed.

4. Once at the start position, the weighted end of the pole can be raised slightly until the lower cable is slack.

5. Both cables can be raised simultaneously until the pivot block is near the top of the spool stack. This may be determined by LED position, encoder readout, and possibly the cable fiducial.

6. The operator pulls back on the sliding plate on the pinblock as both cables are raised. Once the pivot block passes through, the slide plate can be released.

7. The operator detaches the pivot block .

8. Both cables are again raised simultaneously until the top pin of the weighted end segment is near the top of the spool stack.

9. The operator then pulls back on the sliding pin plate and raises both cables until the top pin of the weighted segment is above the pinblock.

10. The sliding pinplate is released and the cable lengths adjusted until the top pin of the weighted segment is securely placed into the torque slot of the pinblock.

11. The operator uses the torque wrench to disengage the cable end segment from the end of the weighted segment.

12. The upper cable is lifted slightly to allow the operator to disengage the internal safety cord.

13. At this time the hook attachment piece can be attached to the cable end BTC. This is done by first attaching the internal cords between the two pieces. Then the operator aligns the castellations and firmly hand tightens the coupling.

14. The operator attaches the hook to the eye ring in the internal cord of the retracted segment.

15. The cable is raised slightly at first to ensure that the hook attachment piece is firmly attached to the cable end BTC. Once this bond is evident, the operator pulls back on the sliding pinplate.

16. Both cables are raised simultaneously until the two upper pins of the segment are above the pinblock. The pinplate can be released.

17. Both cables are raised simultaneously as the next BTC connection is above the pinblock. At this time, the sliding pinplate is again pulled back until the top pin of the next segment is above the pinblock.

18. The top cable is lowered until the top segment pin is securely placed into the torque slot of the pinblock.

19. The BTC coupling is disengaged.

20. The internal safety cord is disengaged.

21. The top segment is now released from the hoist hook and placed onto the glovebox rack.

22. The male coupling side of the next weighted segment to be used (as marked in the glovebox) is placed onto the hoist hook.

23. From this point on, the regular assembly procedure can followed, substituting a different weighted segment at the end to allow for calibration at a different radial position.
24. The procedures for Attaching the Pivot Block, and Cable Position Calibration can now be followed.
25. At this time changes in theta position can be implemented, and a new data set at a different radial position can be acquired.

D.12 Retrieval of Pole Assembly

1. Once calibration is complete, the system can be retracted weight end first for disassembly.
2. The cables can be moved back to the "start" position. This motion will be determined and run by the preset program, to avoid interference in the "excluded" region.
3. PMT high voltage will be turned off, and the cameras and LEDs turned on. The light cover can also be removed.
4. Once at the start position, the weighted end of the pole can be raised slightly until the lower cable is slack.
5. Both cables can be raised simultaneously until the pivot block is near the top of the spool stack. This may be determined by LED position, encoder readout, and possibly the cable fiducial.
6. The operator pulls back on the sliding plate on the pinblock as both cables are raised. Once the pivot block passes through, the slide plate can be released.
7. The operator detaches the pivot block .
8. Both cables are again raised simultaneously until the top pin of the weighted end segment is near the top of the spool stack.
9. The operator then pulls back on the sliding pin plate and raises both cables until the top pin of the weighted segment is above the pinblock.

10. The sliding pinplate is released and the cable lengths adjusted until the top pin of the weighted segment is securely placed into the torque slot of the pinblock.
11. The operator uses the torque wrench to disengage the cable end segment from the end of the weighted segment.
12. The upper cable is lifted slightly to allow the operator to disengage the internal safety cord.
13. At this time the hook attachment piece can be attached to the cable end BTC. This is done by first attaching the internal cords between the two pieces. Then the operator aligns the castellations and firmly hand tightens the coupling.

D.13 Disassembly

1. The top cable is lowered so that the hook is above the top of the retracted segment.
2. The operator attaches the hook to the eye ring in the internal cord of the retracted segment.
3. The cable is raised slightly at first to ensure that the hook attachment piece is firmly attached to the cable end BTC. Once this bond is evident, the operator pulls back on the sliding pinplate.
4. Both cables are raised simultaneously until the two upper pins of the segment are above the pinblock. The pinplate can be released.
5. Both cables are raised simultaneously as the next BTC connection is above the pinblock. At this time, the sliding pinplate is again pulled back until the top pin of the next segment is above the pinblock.
6. The top cable is lowered until the top segment pin is securely placed into the torque slot of the pinblock.
7. The BTC coupling is disengaged.
8. The internal safety cord is disengaged.

9. The top segment is now released from the hoist hook and placed onto the glovebox rack.
10. The above disassembly procedure is repeated until the entire pole assembly is retracted and stored safely in the glovebox.
11. Care should be taken upon retraction of segment 3, which requires sliding of the pinplate to allow the cable to pass through the pinblock.
12. All electrical connections need to be disconnected as they enter the glovebox.
13. After the second segment is retracted, the 16" gate valve can be closed. At this time detector high voltage can be turned on.
14. Once the source is retracted, the 6 gate valve can be closed.
15. At this time, purging of the spool stack, glovebox, and transfer box can begin. Sources can be removed from the glovebox at appropriate times during the purging procedure.

E Weight of the Glovebox Extension

Glovebox			**Density of St. Steel (lbs/cu in):**	**0.29**
Penthouse - Est Weight			**Density of 3/8 Acrylic (lbs/cu in):**	**0.04**
			Wall Thickness of Glovebox:	**0.125**
Parts	**Volume**	**Weight**		
Front Window Frame	43.52618	12.62259		
Back Window Frame	43.52618	12.62259		
Side A Window Frame	31.86295	9.240256		
Side B Window Frame	31.86295	9.240256		
Base Plate	51.1875	14.84438		
Top Plate	47.7	13.833		
Sub-Total		**72.40307**		
Front Window	282.8304	11.47034		
Back Window	282.8304	11.47034		
Side A Window	123.2473	4.998362		
Side B Window	123.2473	4.998362		
Total Weight (lbs)		**105.3405**		

Figure 38: Weight calculation for the glovebox extension.

F Specifications of Pressure Transducers

Model 85 UltraStable

ICSENSORS

316L SS Pressure Sensor
High Performance, Small Profile
0-100 mV Output
Absolute and Gage
Low Pressure

- **Hydraulic Controls**
- **Process Control**
- **Oceanography**
- **Refrigeration/Compressors**
- **Pressure Transmitters**
- **Level Systems**

DESCRIPTION

This ia a micromachined piezoresistive silicon pressure sensor. It is designed for OEM applications where compatibility with corrosive media must be maintained. The sensor chip is mounted on a TO style header, which is resistance welded to a 316 stainless steel package. A 316 stainless steel convoluted isolation diaphragm is welded to the package, sealing a small volume of silicone oil between the diaphragm and the sensor chip. The ISO pressure housing utilizes the oil column to couple the piezoresistive sensor to the isolation diaphragm. A thickfilm ceramic compensation board with laser trimmed resistors, and an additional gain set resistor to normalize pressure sensitivity are an integral part of the sensor package. A variety of threaded process fittings are available. Fittings include standards like 1/4 and 1/8 NPT, 1/4 BSP as well as custom process fittings. Electrical options include cable and connector.

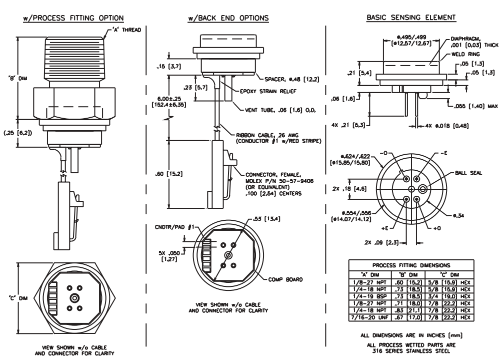
FEATURES

- Weldable and O-Ring Flush Mount
- -20°C to +85°C Compensated Temperature Range
- +0.1% Pressure Non-linearity
- +1.0% Interchangeable Span (provided by gain set resistor)
- Solid State Reliability
- Low Power

STANDARD RANGES

Range	psig	psia
0 to 15	●	●
0 to 30	●	●
0 to 50	●	●
0 to 100	●	●
0 to 300	●	●
0 to 500	●	●

DIMENSIONS



PROCESS FITTING DIMENSIONS		
"A" DIM	"B" DIM	"C" DIM
1/8-27 NPT	.60 [15.2]	5/8 [15.9] HEX
1/4-18 NPT	.73 [18.5]	5/8 [15.9] HEX
1/4-19 BSP	.73 [18.5]	3/4 [19.0] HEX
1/8-27 NPT	.71 [18.0]	7/8 [22.2] HEX
1/4-18 NPT	.83 [21.1]	7/8 [22.2] HEX
7/16-20 UNF	.67 [17.0]	7/8 [22.2] HEX

1-68 ISO – Wide Temperature Range

Figure 39: Specifications of the pressure transducers.

G Technical Drawings

The technical drawings shown in this Appendix should be considered preliminary unless indicated otherwise. Some of the design details are still be subject to change and review.

The drawings are current as of November 20, 2003.

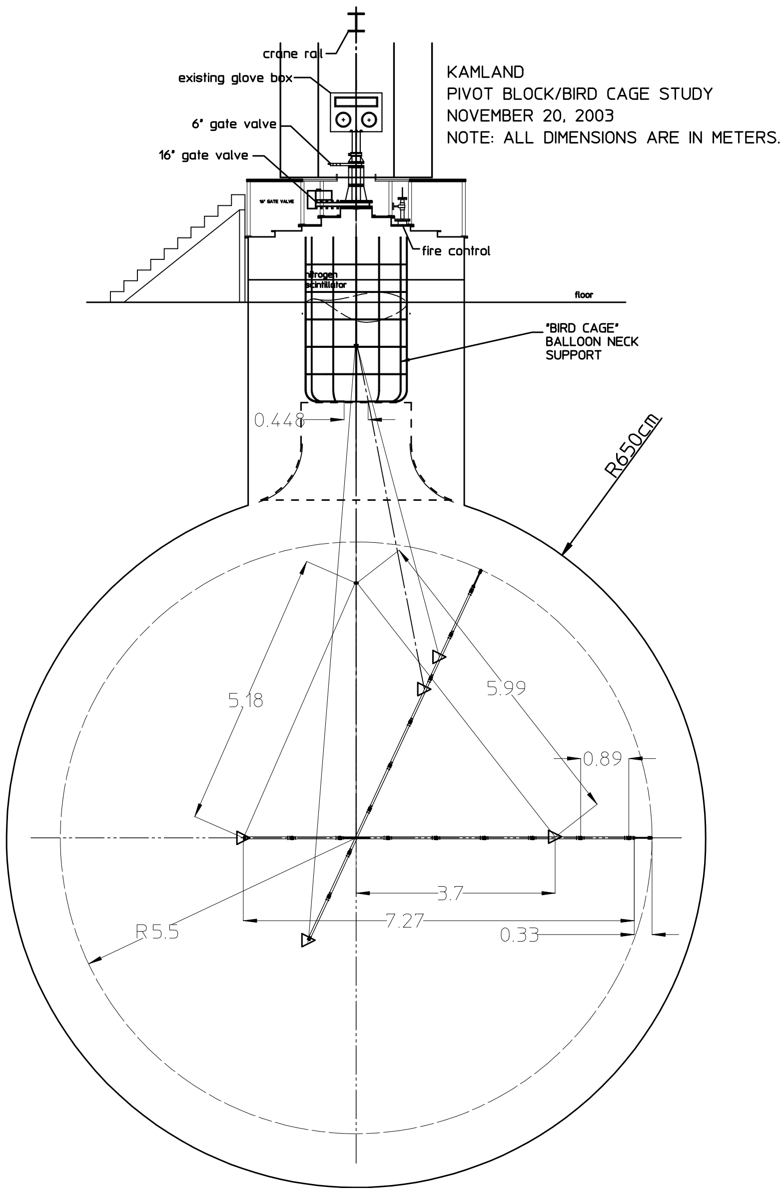


Figure 40: Detector cross-section and illustration of calibration pole with control cables.

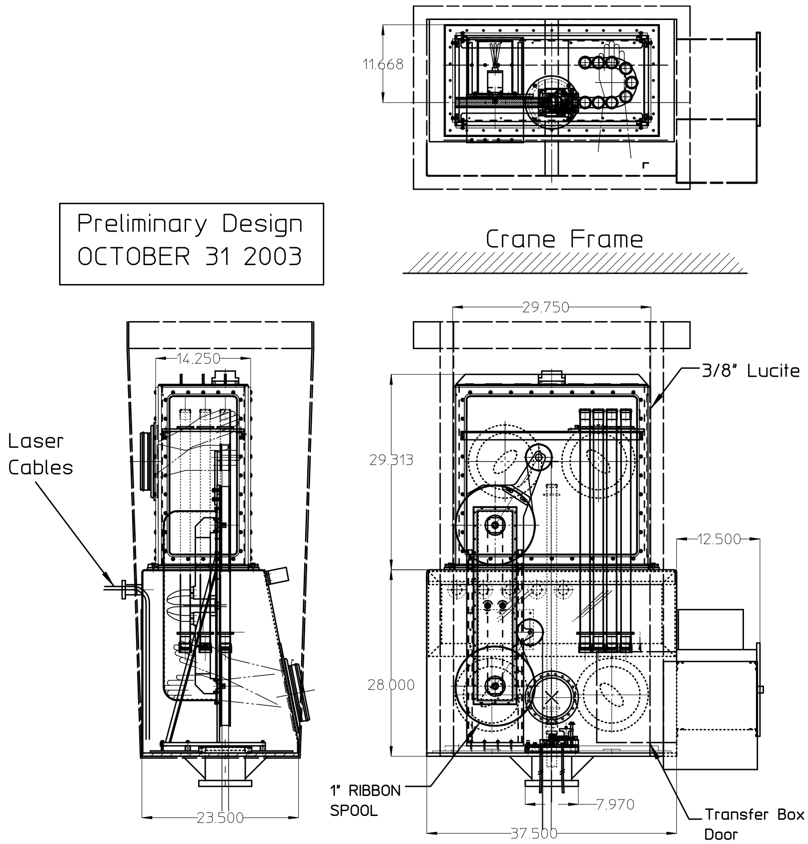


Figure 41: Deployment system layout.

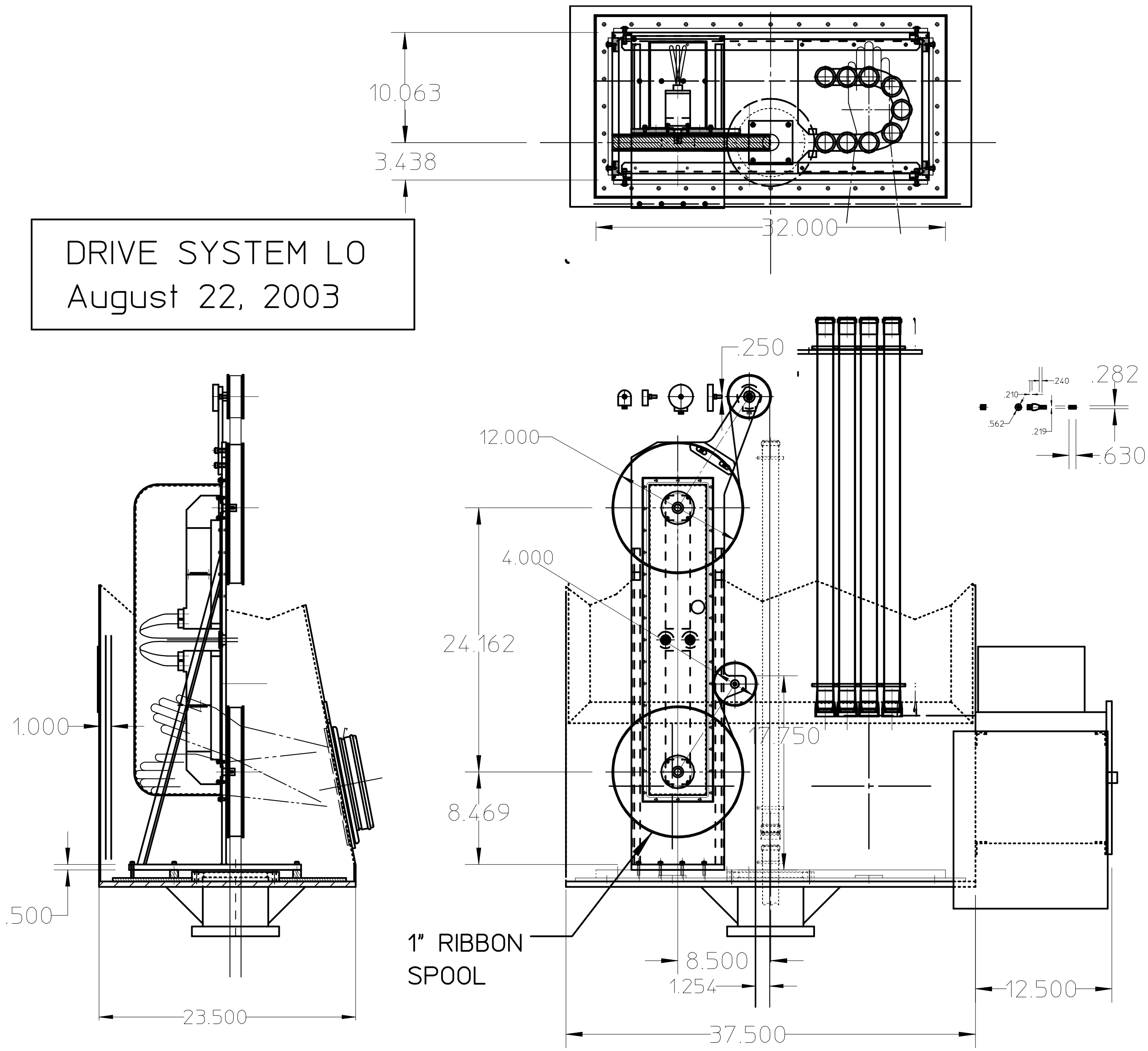


Figure 42: Drive system layout.

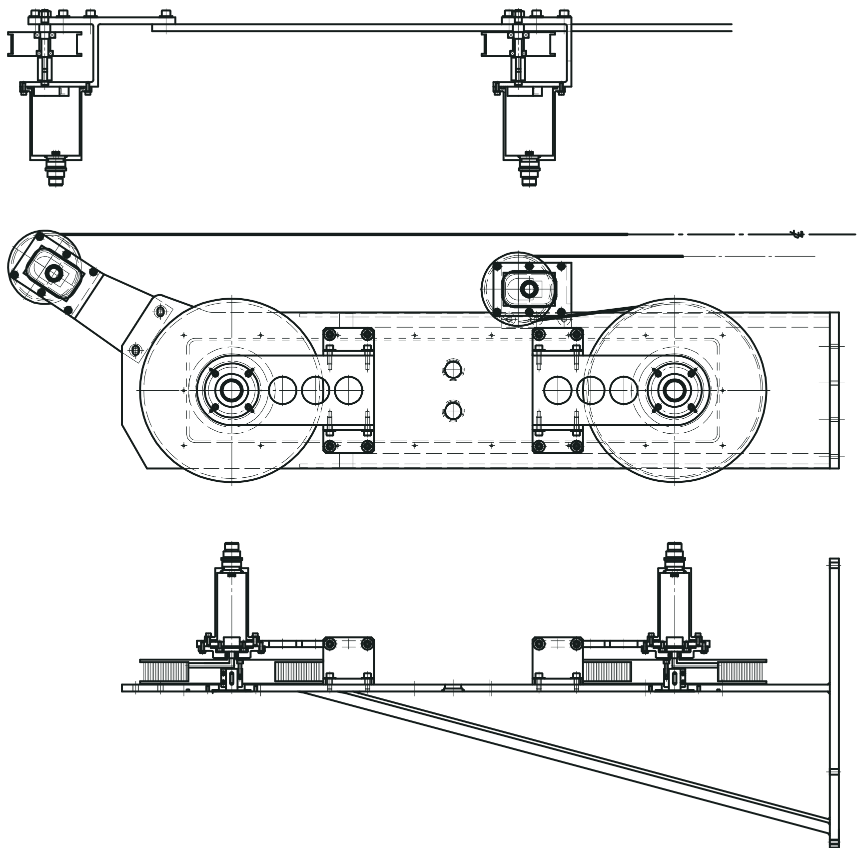


Figure 43: Drive spools layout.

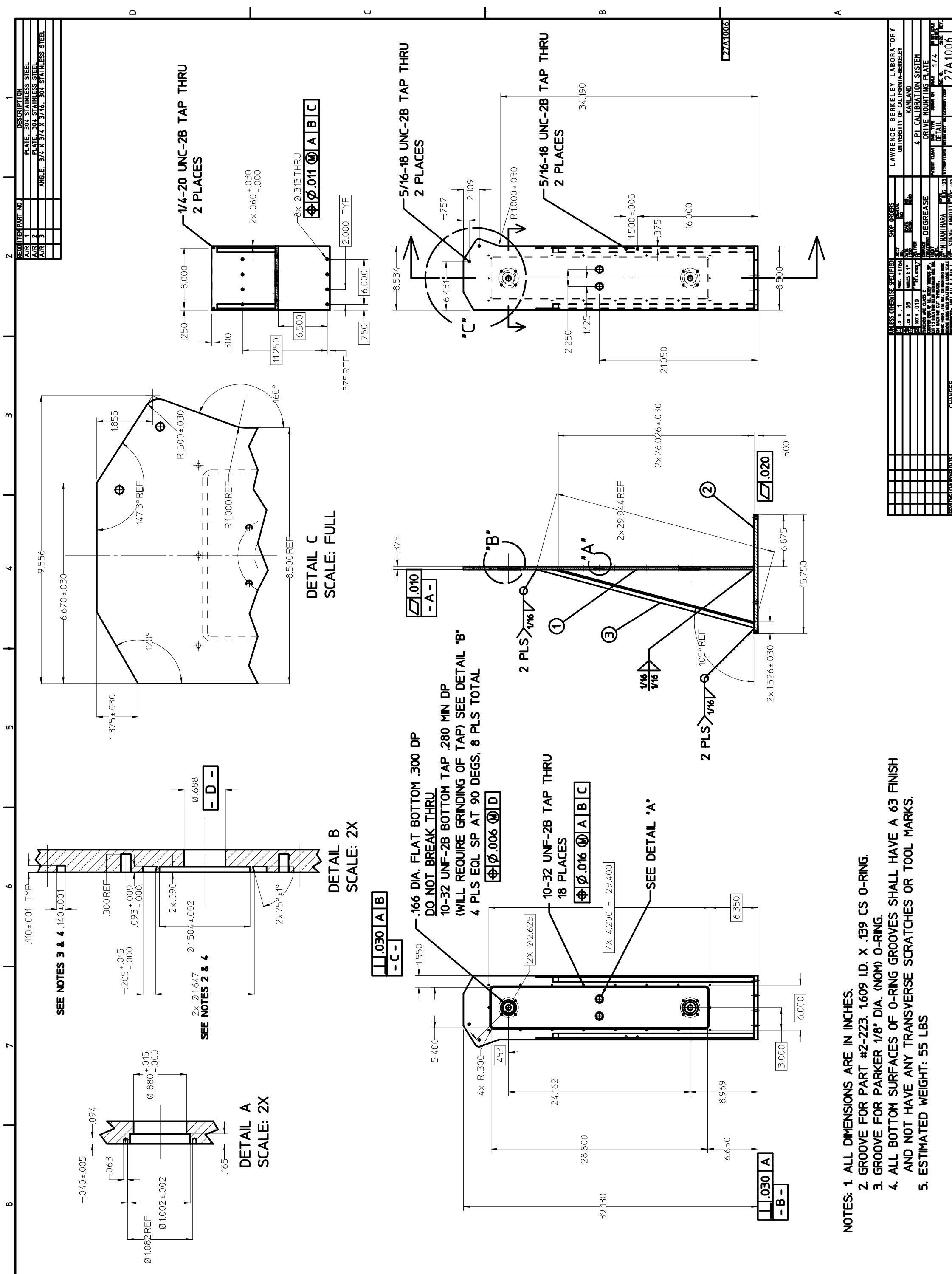


Figure 44: Drive mounting plate.

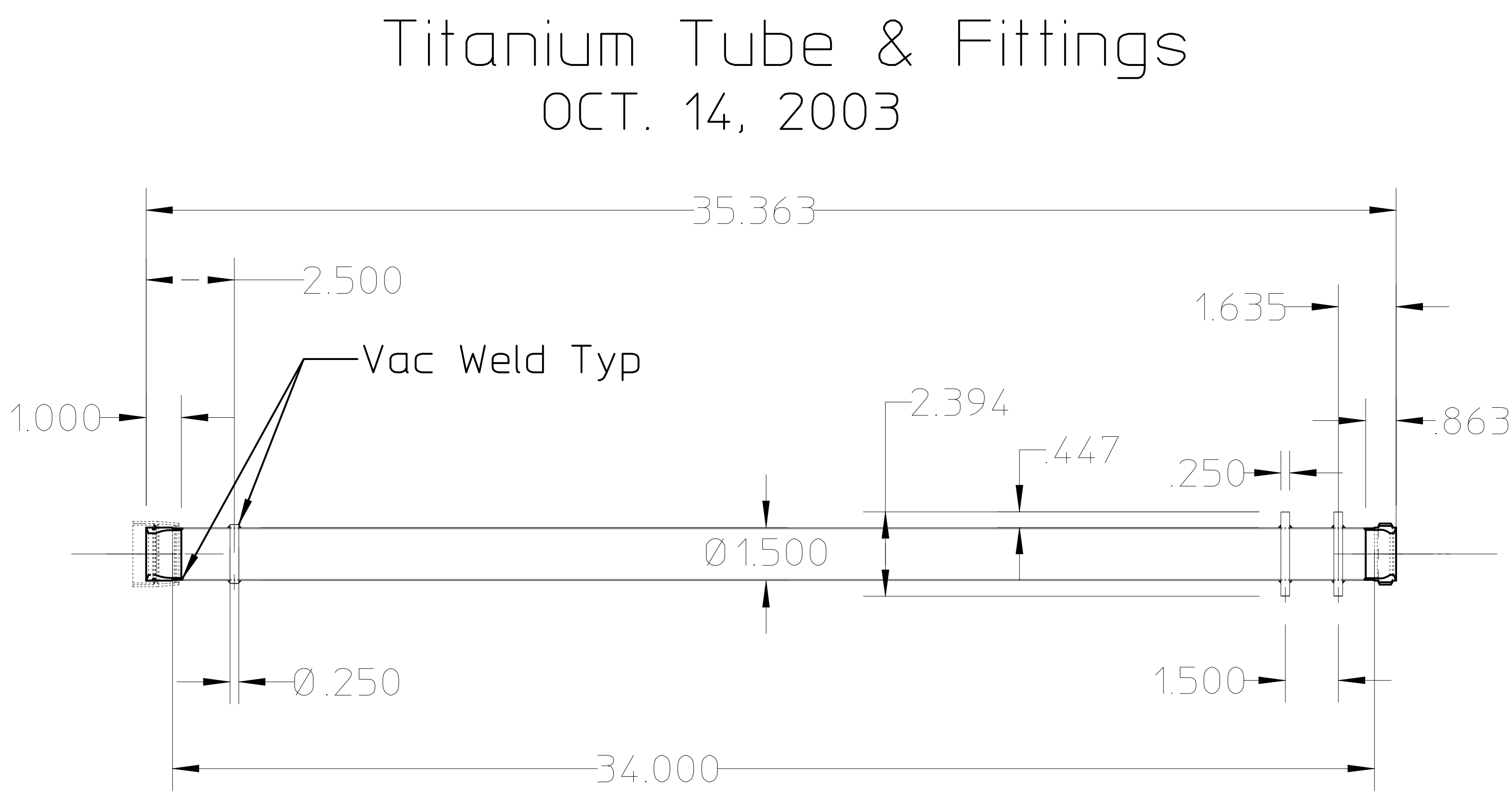


Figure 45: Pole segment with pins and BTC fittings.

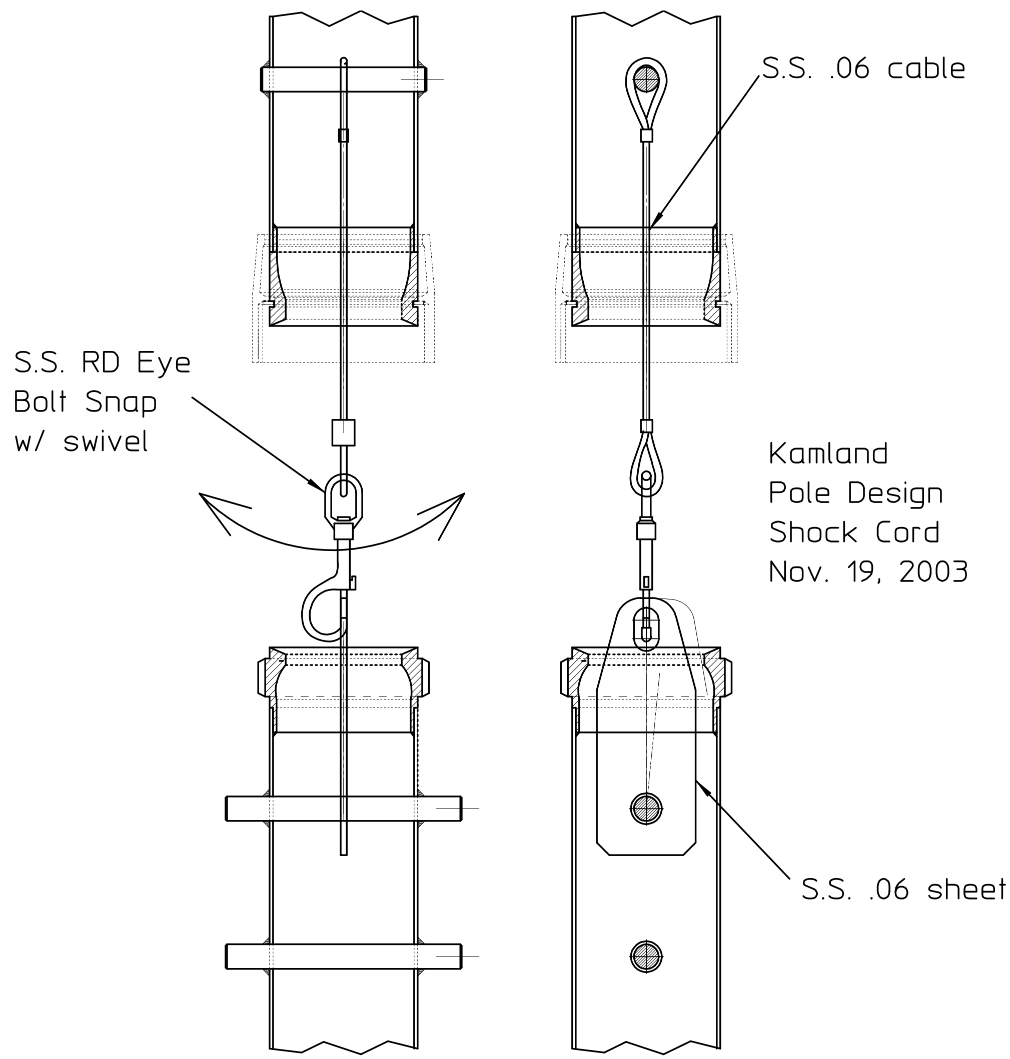


Figure 46: Internal safety line between pole segments. Provides backup connection between individual pole segments in case the BTC fails or is incorrectly assembled.

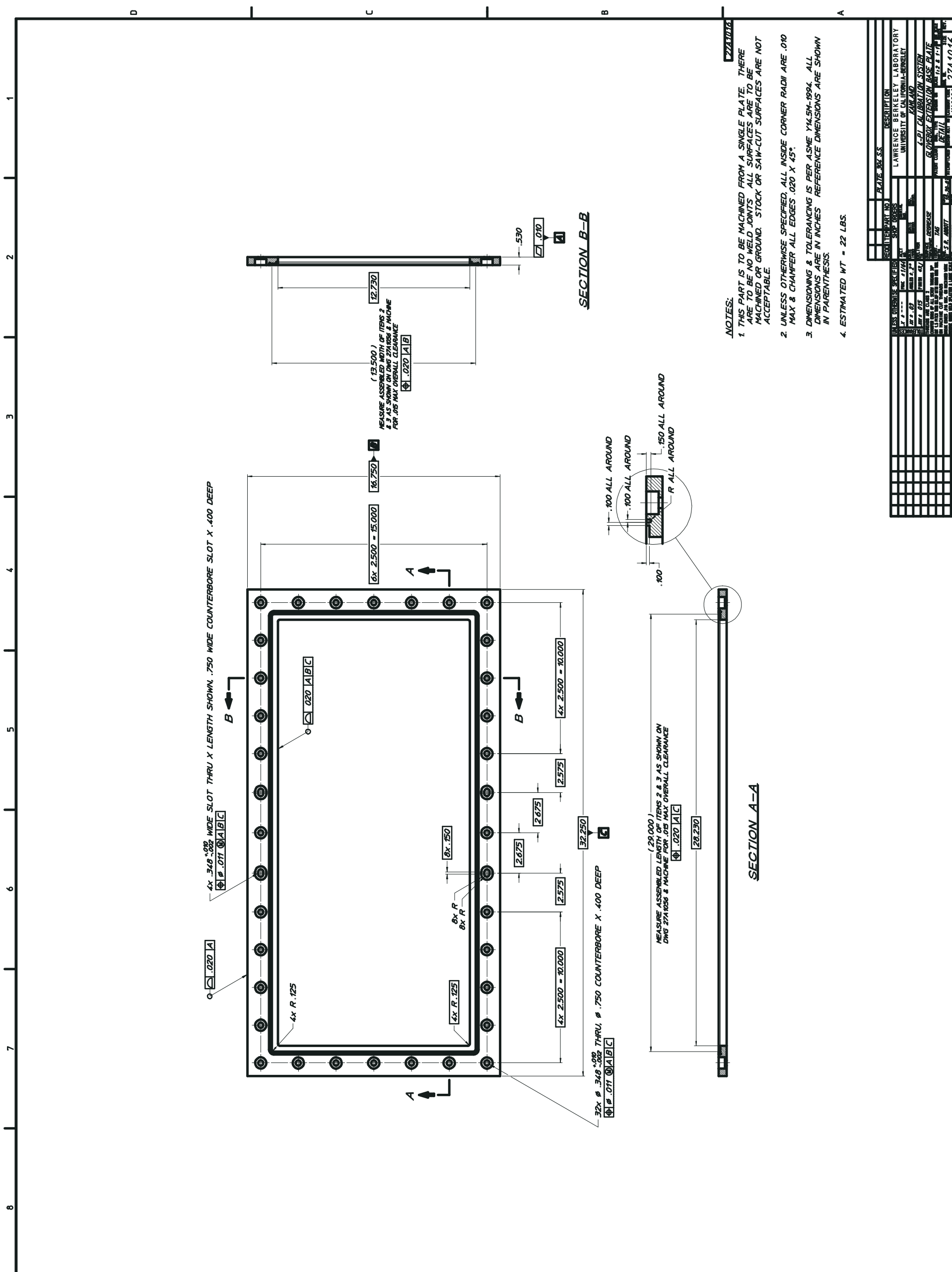


Figure 47: Glovebox extension base plate.

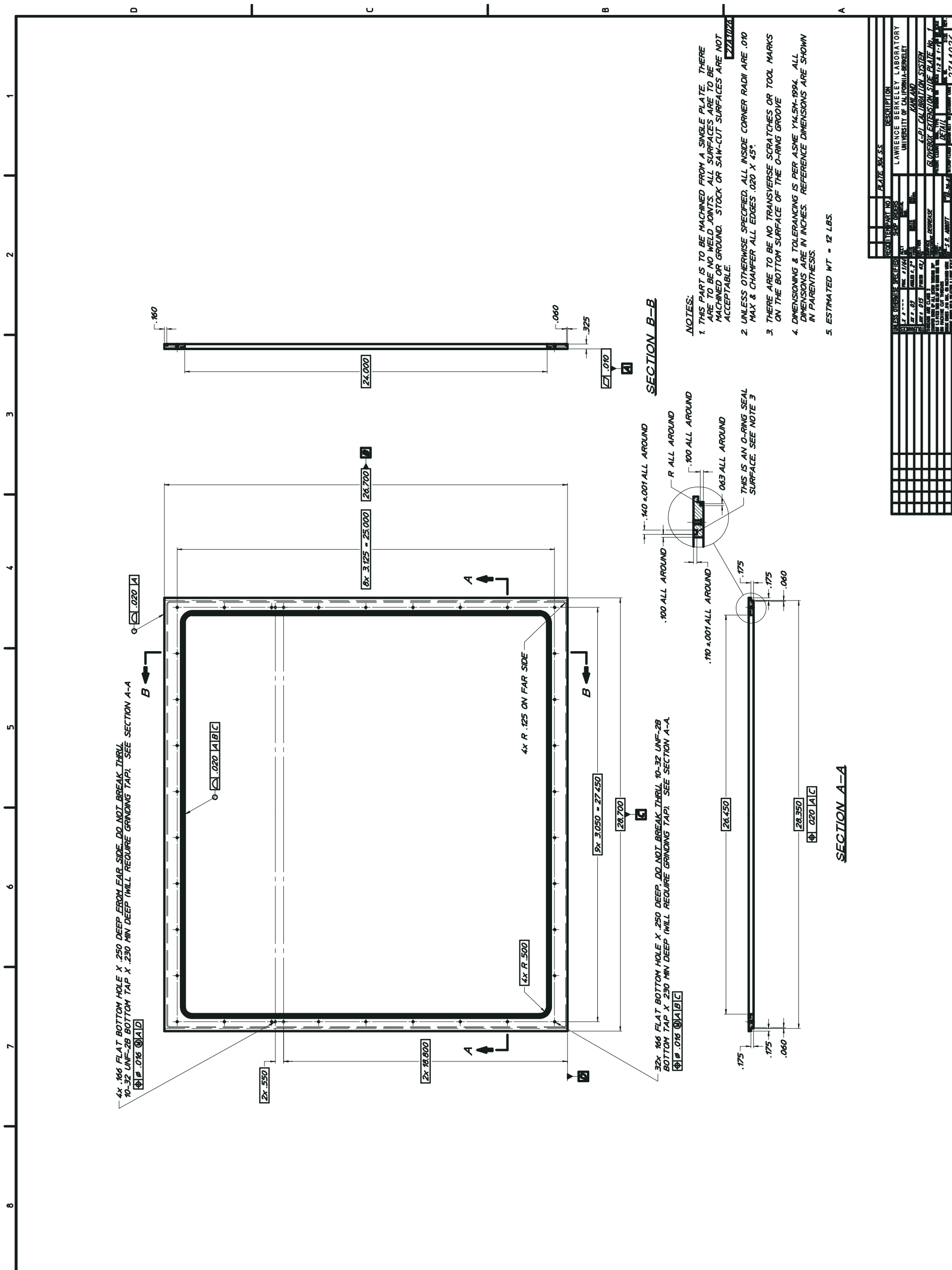


Figure 48: Gloevbox extension side plate No.1.

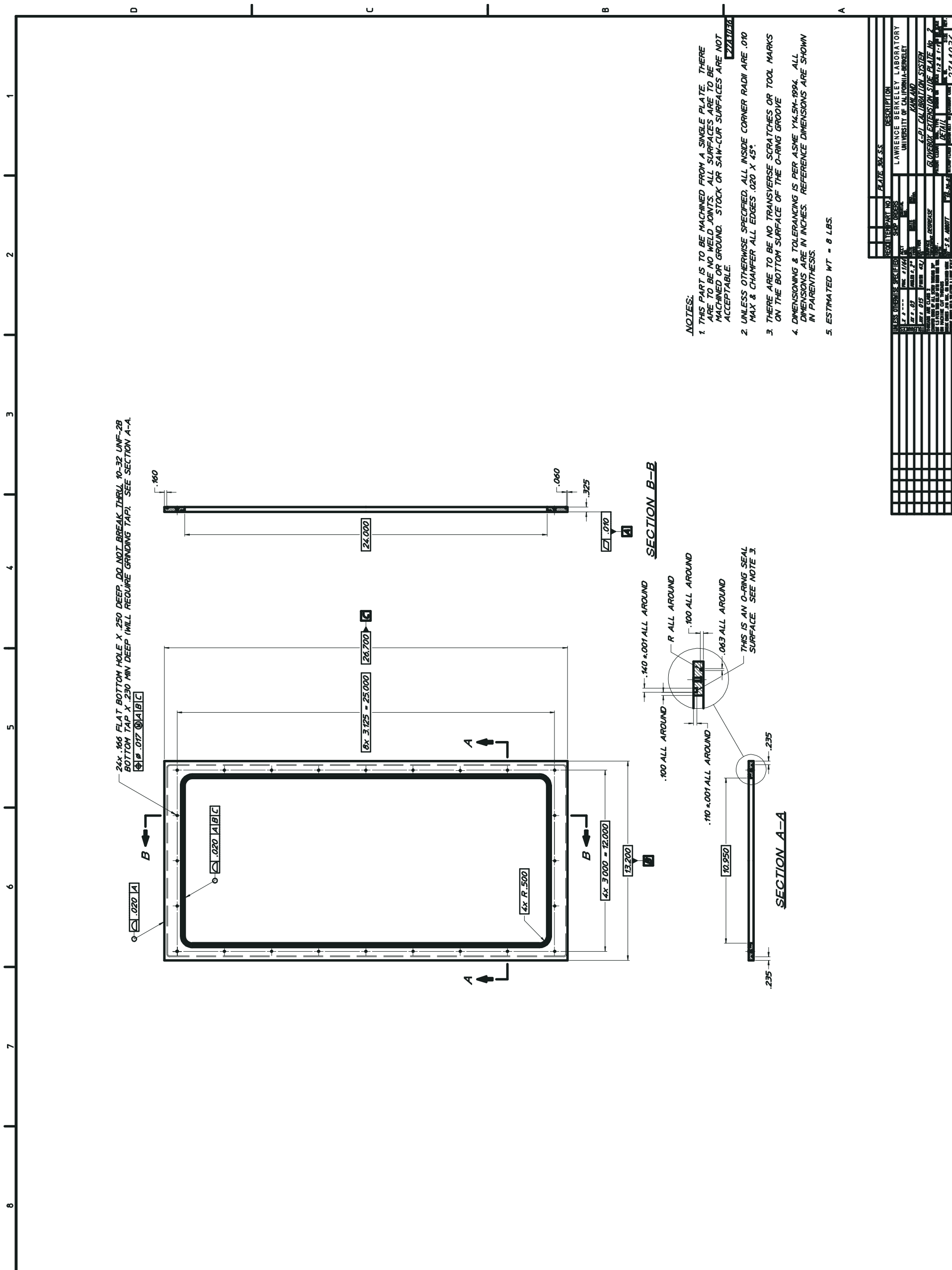


Figure 49: Glovebox extension side plate No.2.

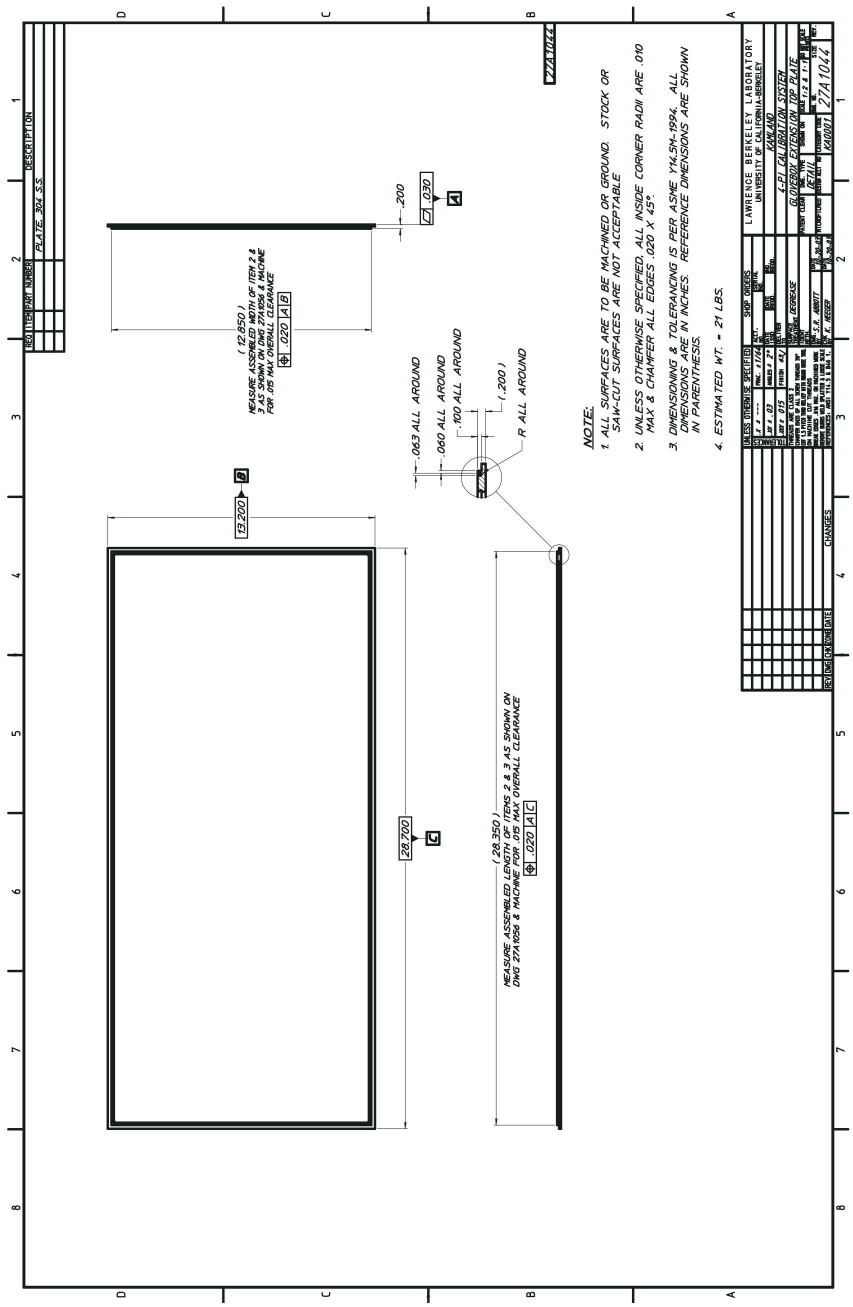


Figure 50: Glovebox extension top plate.

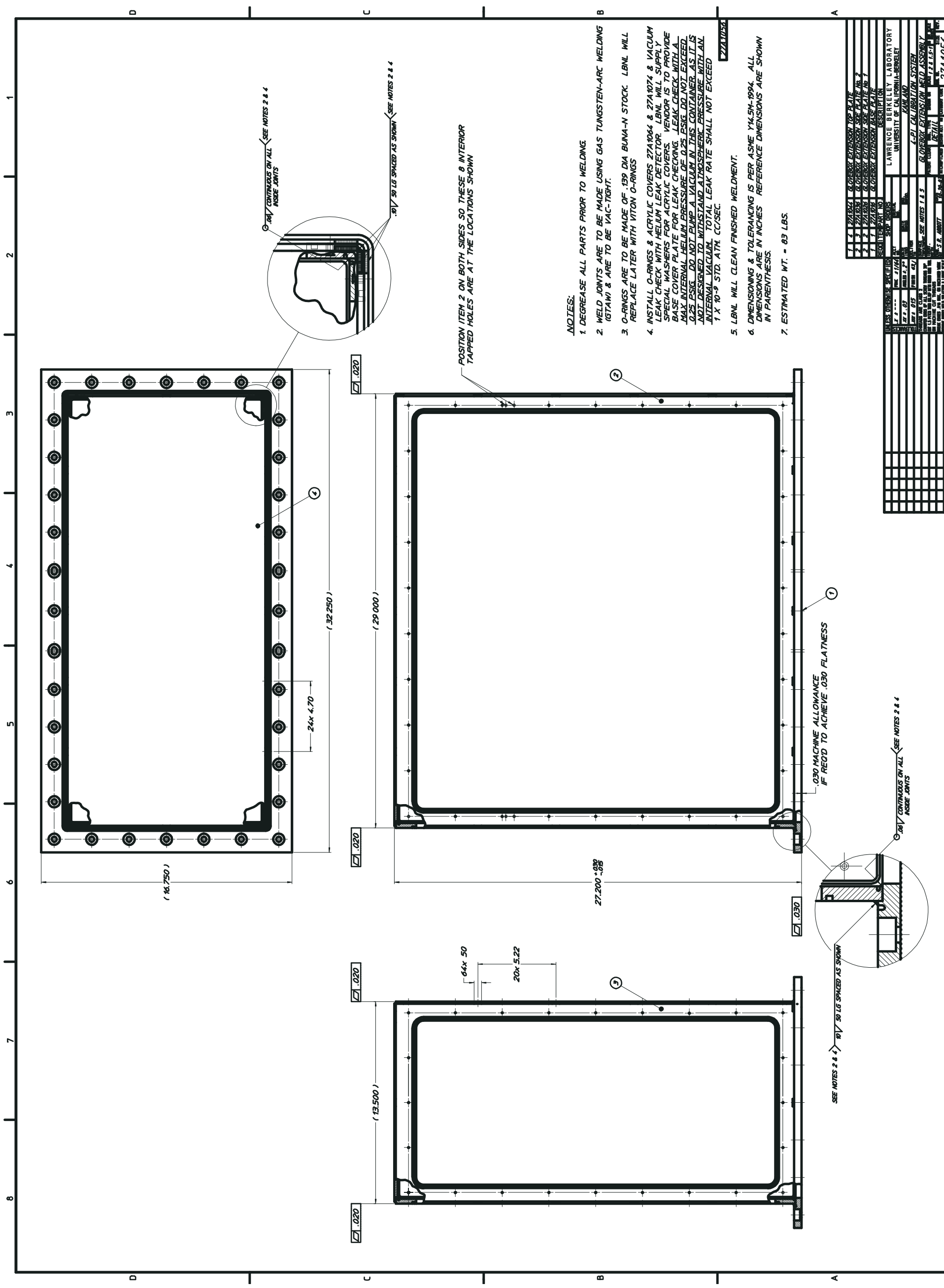


Figure 51: Glovebox extension weld assembly.

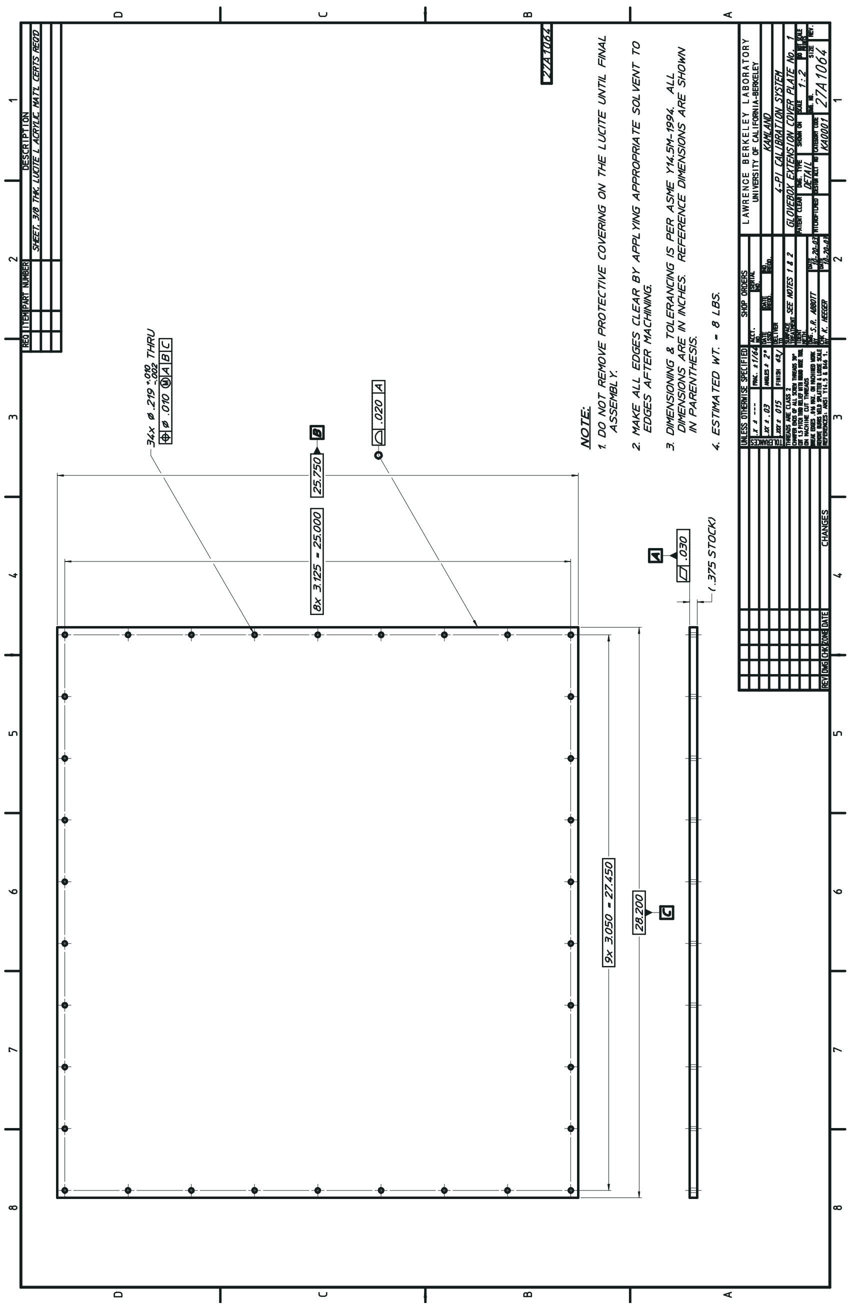


Figure 52: Glovebox extension cover plate No.1.

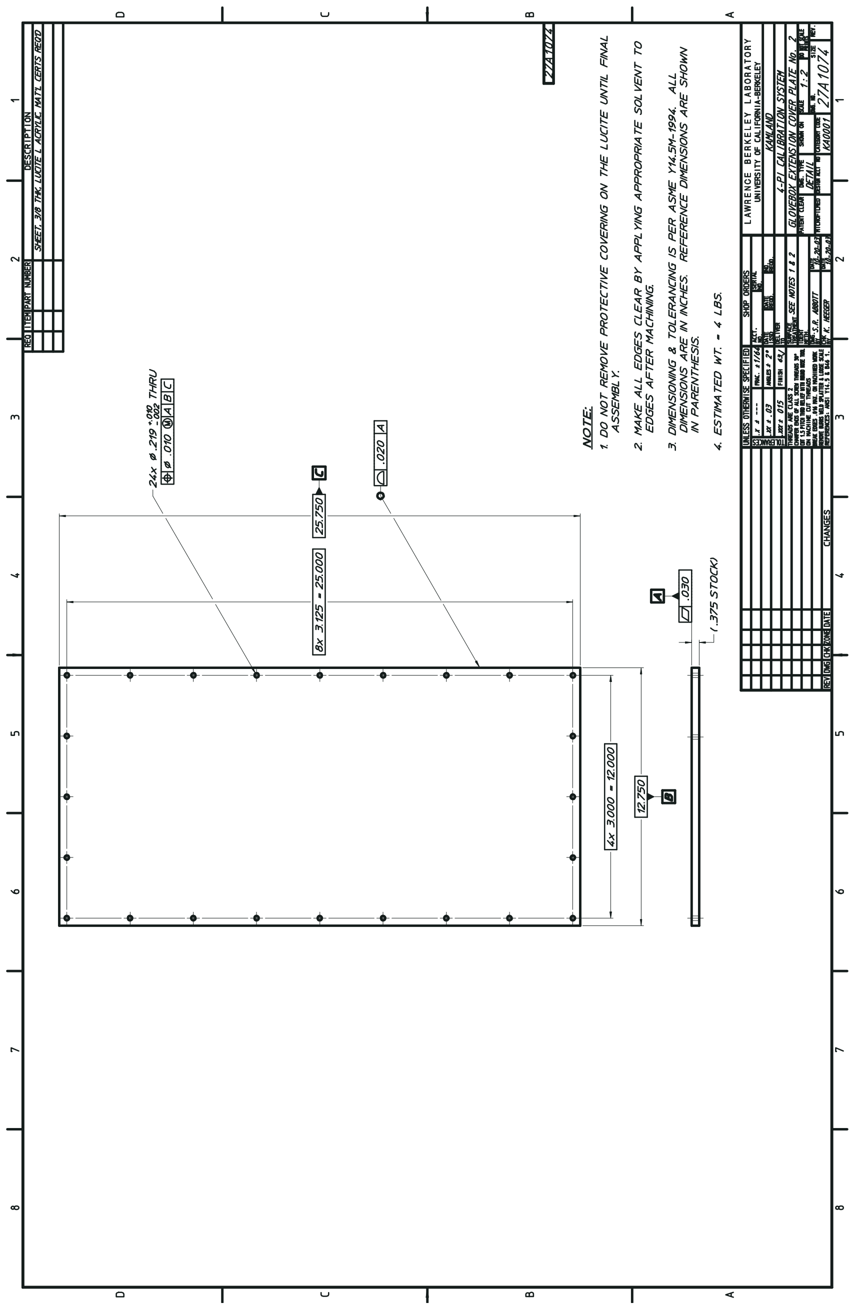


Figure 53: Glovebox extension cover plate No.2.

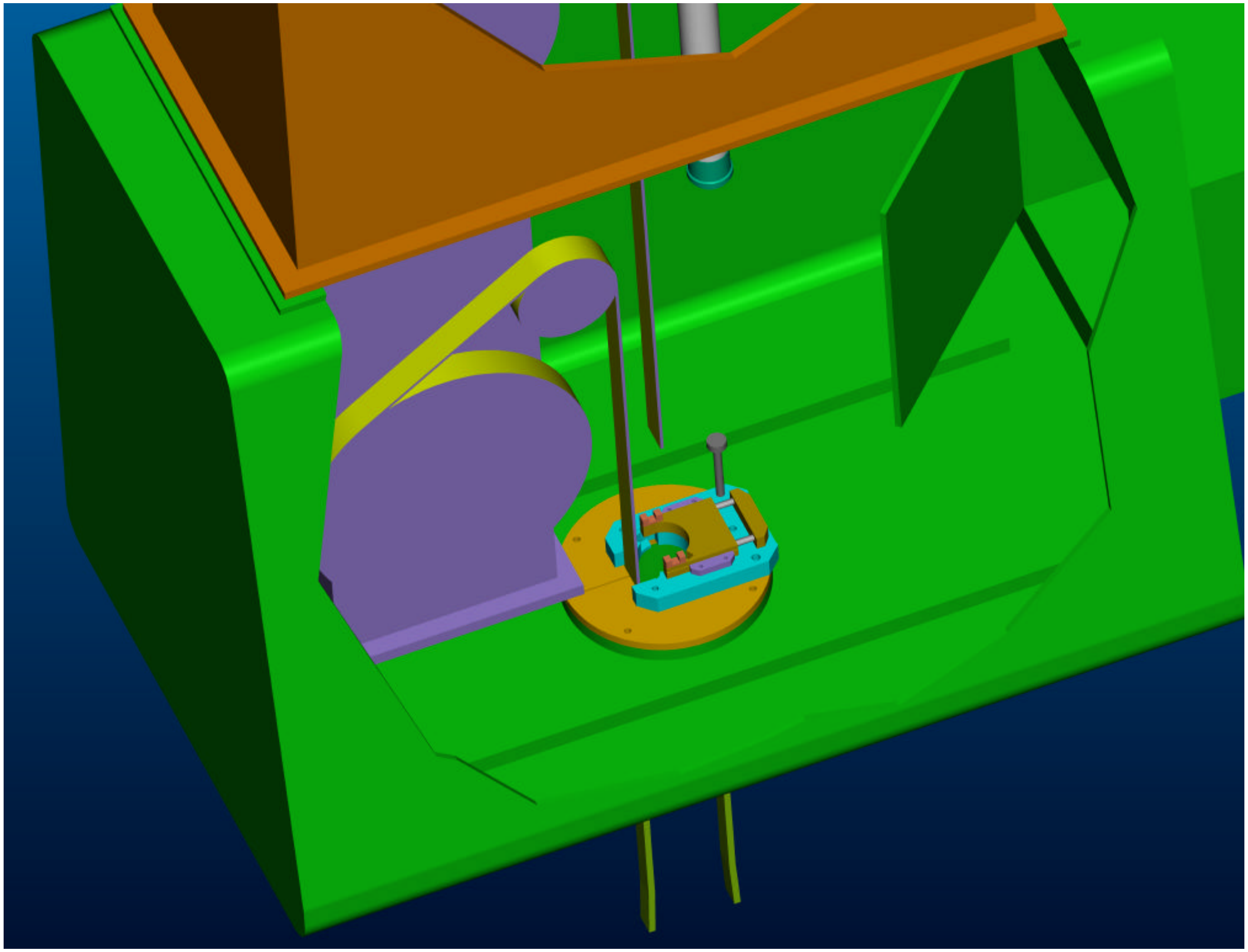


Figure 54: Illustration of the pin block mounted inside the glovebox. The control cables are shown to connect to the pole through the pin block.

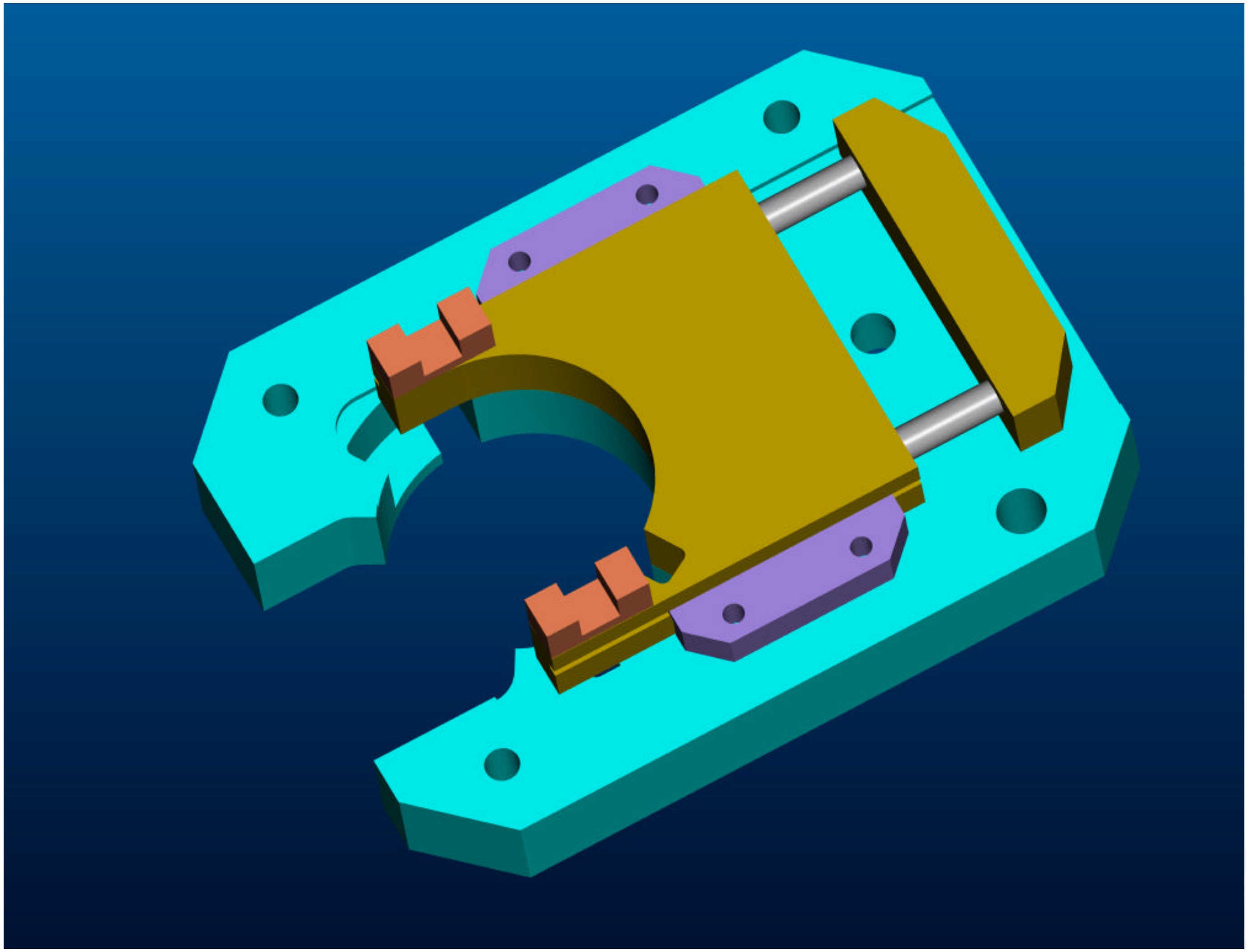


Figure 55: Illustration of the pin block. The spring-loaded top (brown) part slides back and allows for an easy retrieval of the pole segments.

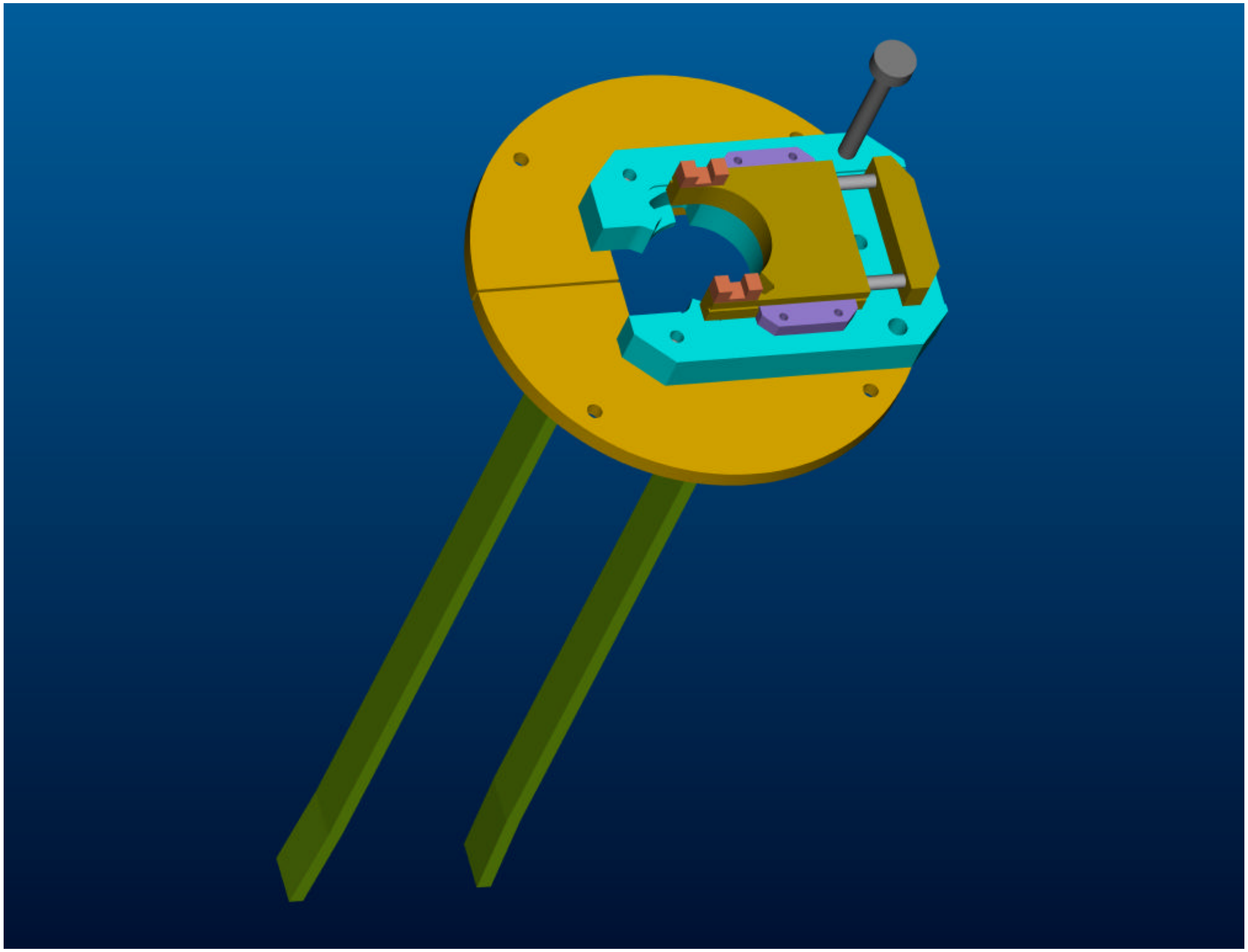


Figure 56: Illustration of the pin block and mounting plate: The pin block is mounted on a split mounting plate that connects to the flange. The split mounting plate allows the easy disassmebly of the system in case of an emergency. The side plates act as guide during the retrieval and prevent the pole from swinging sideways during assembly and disassembly.

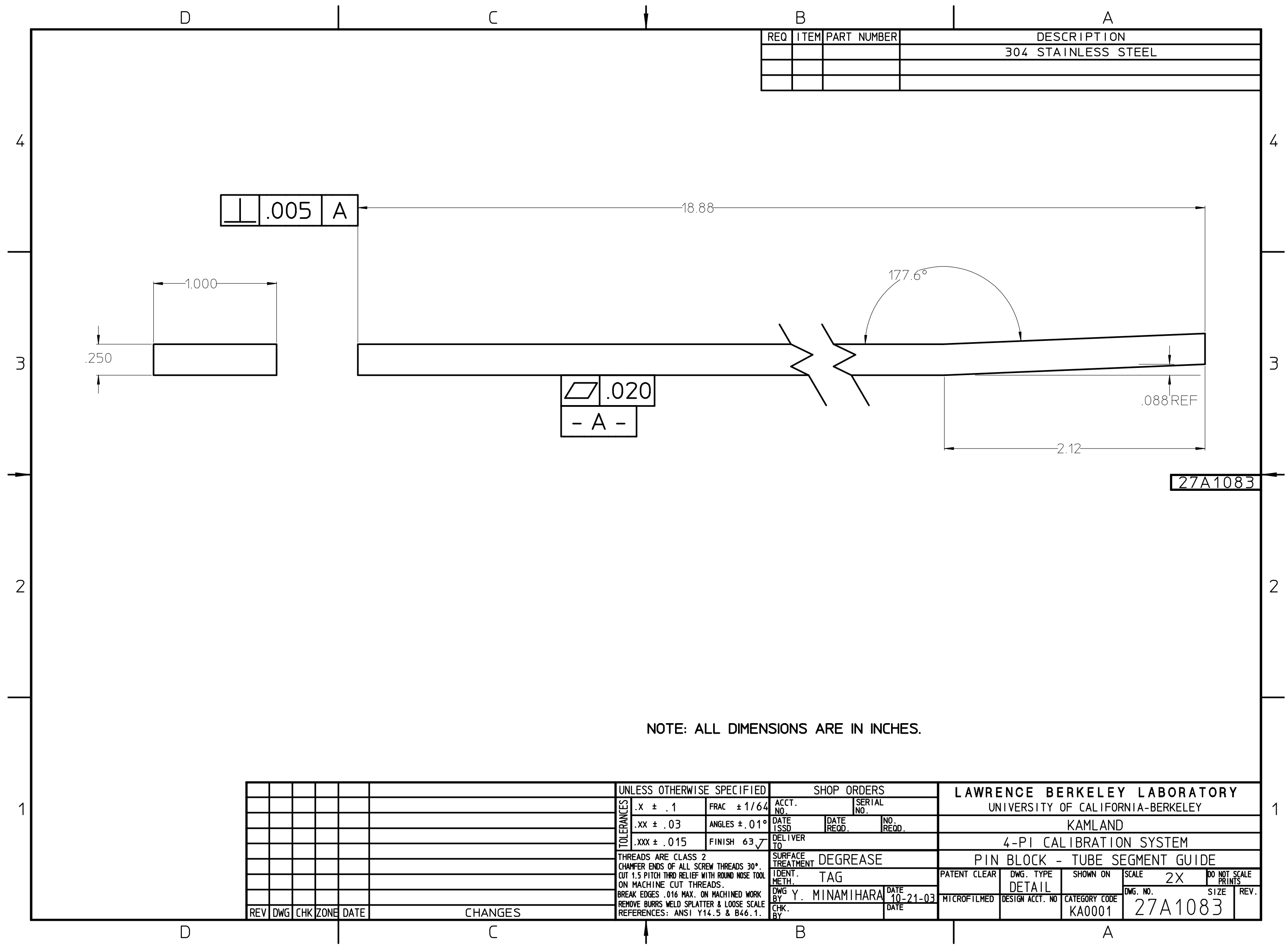


Figure 57: Pin block: tube segment guide.

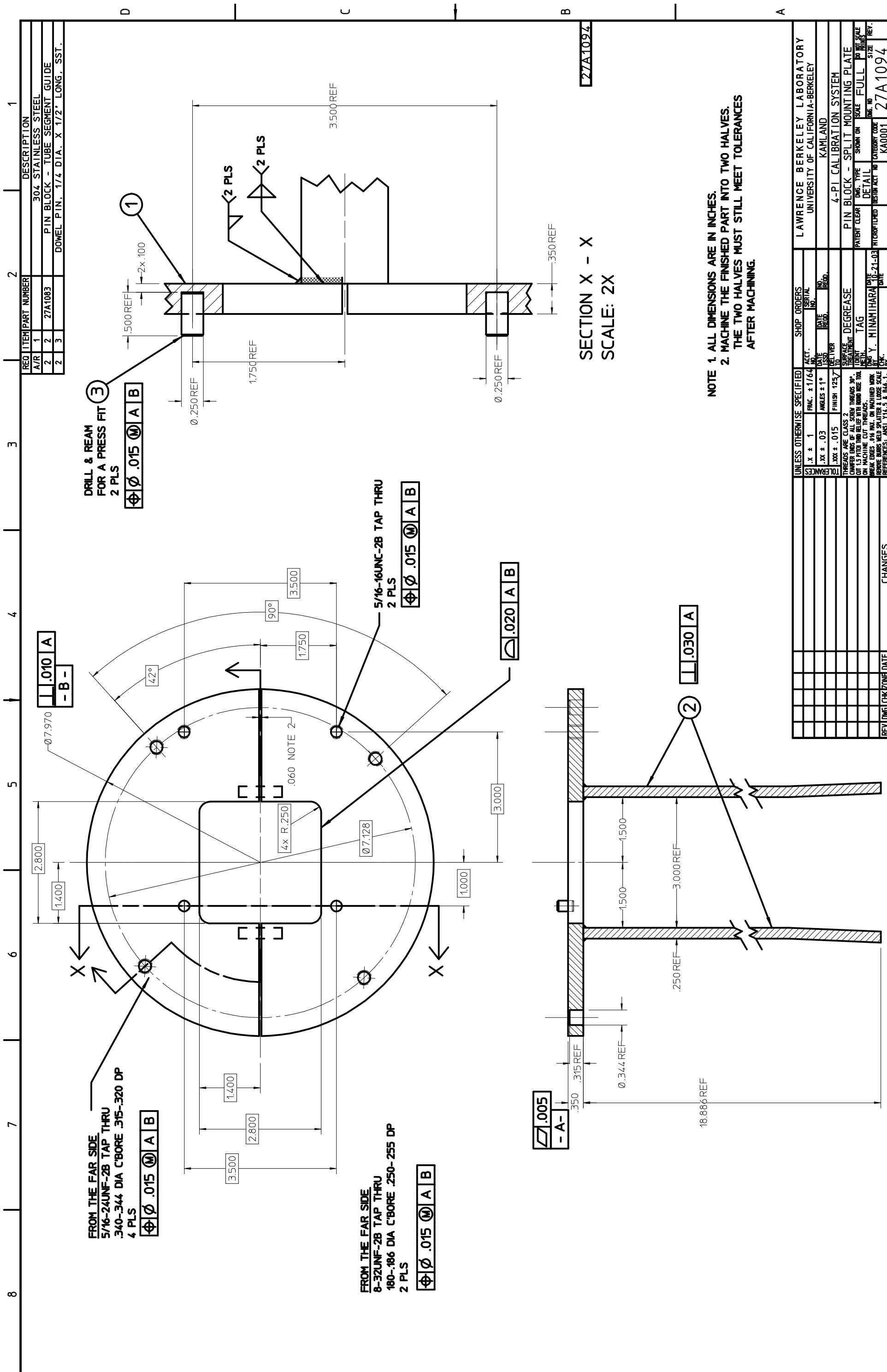


Figure 58: Pin block: split mounting plate.

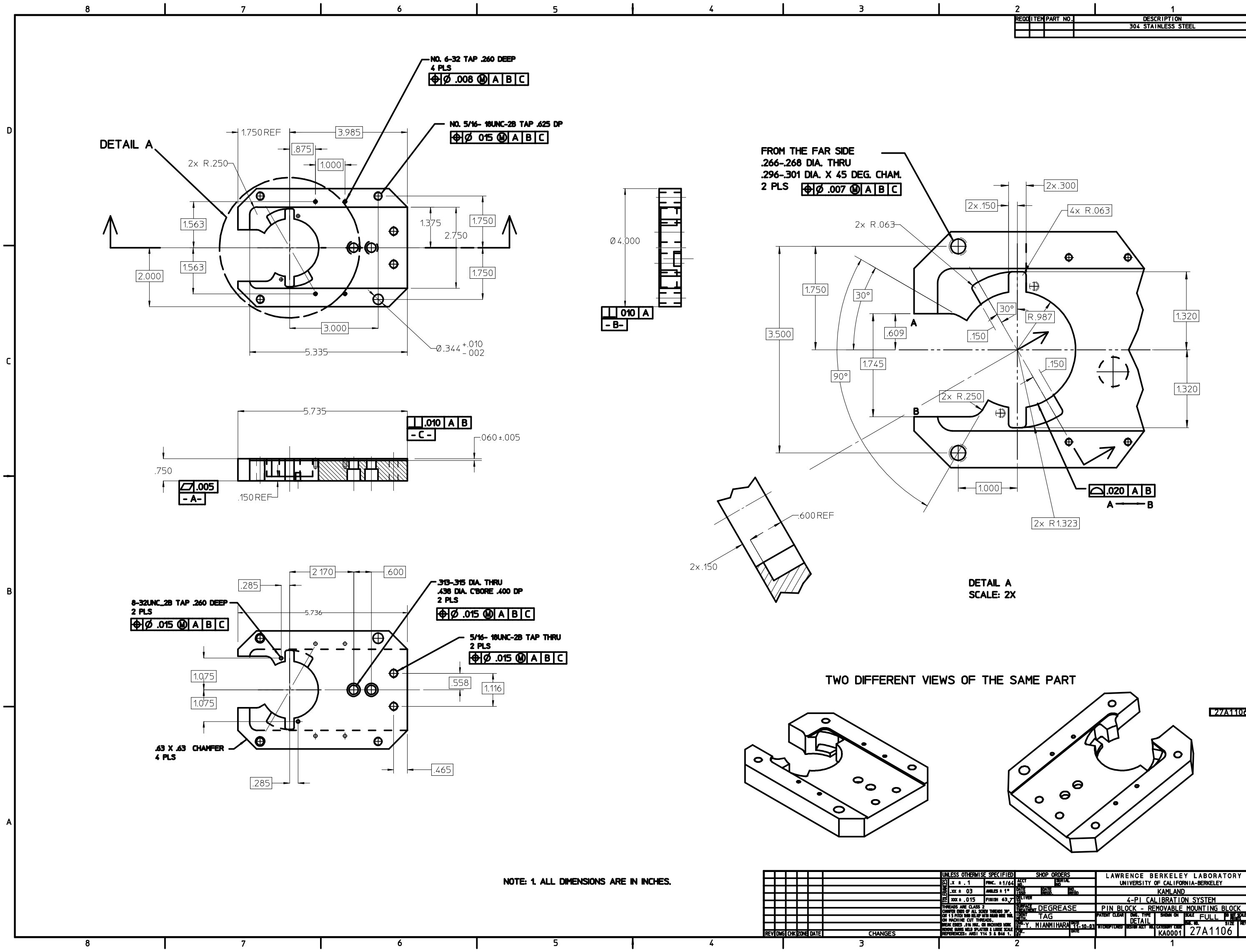


Figure 59: Pin block: removable mounting block.

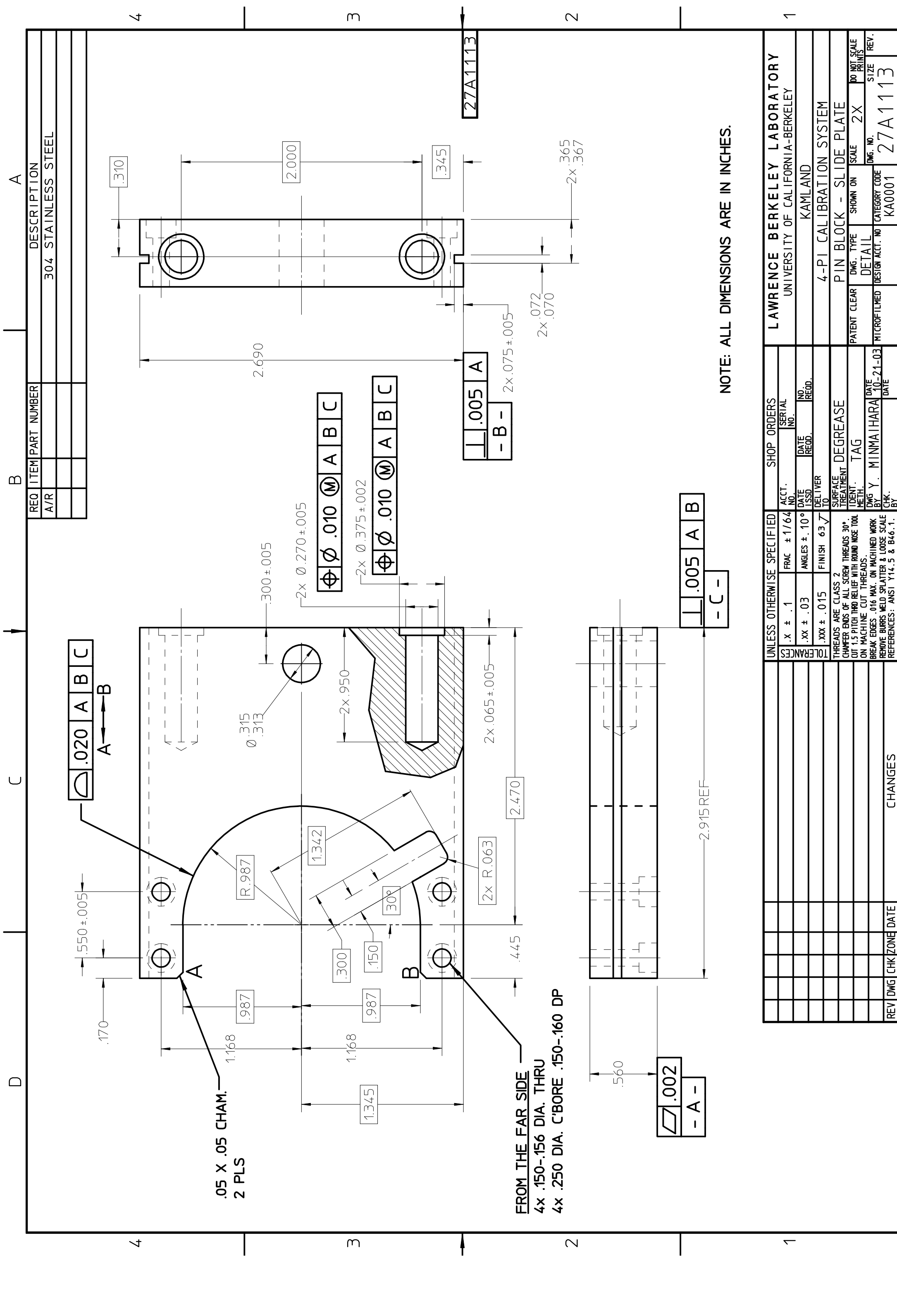


Figure 60: Pin block: slide plate.

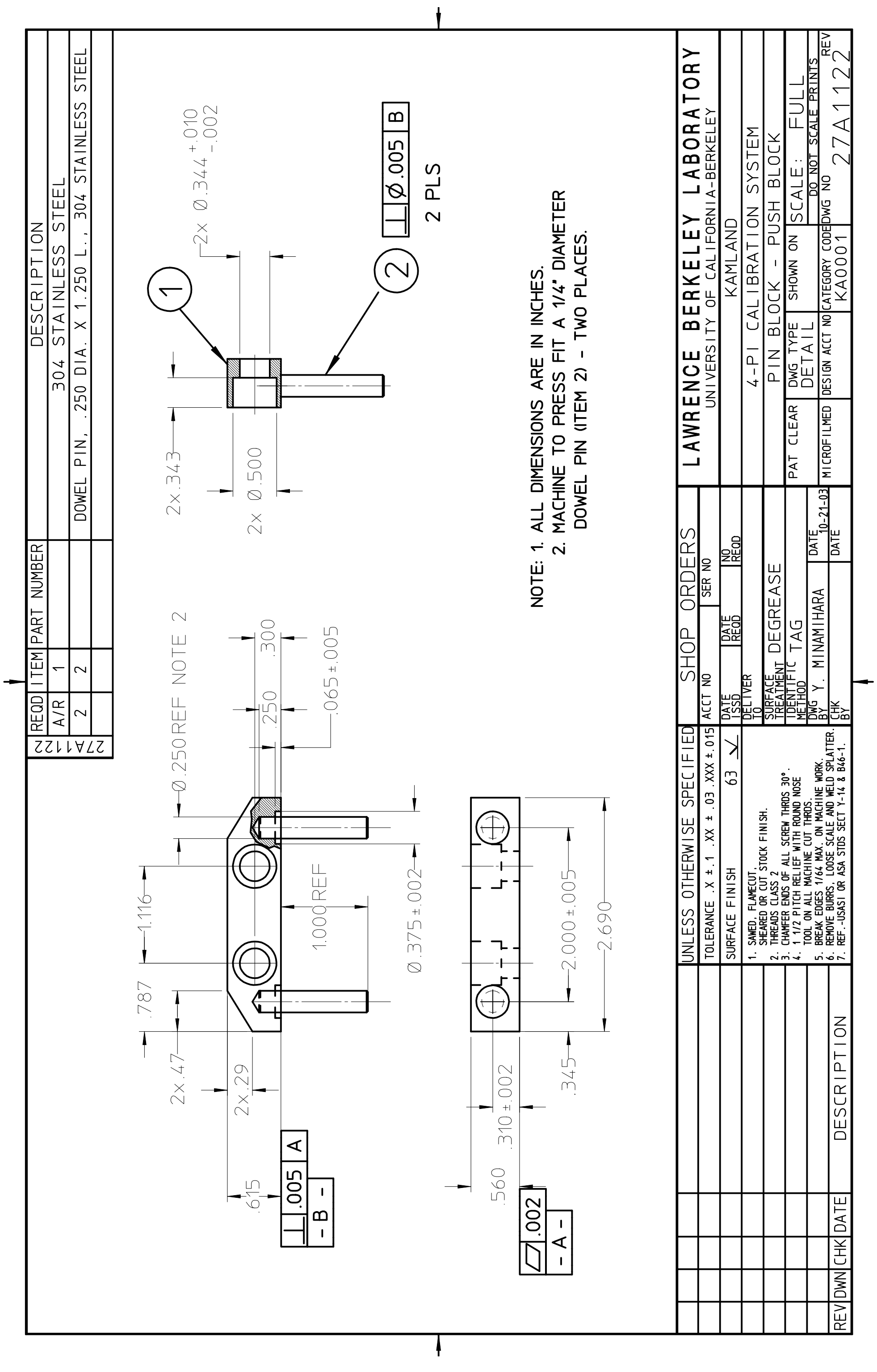


Figure 61: Pin block: push block.

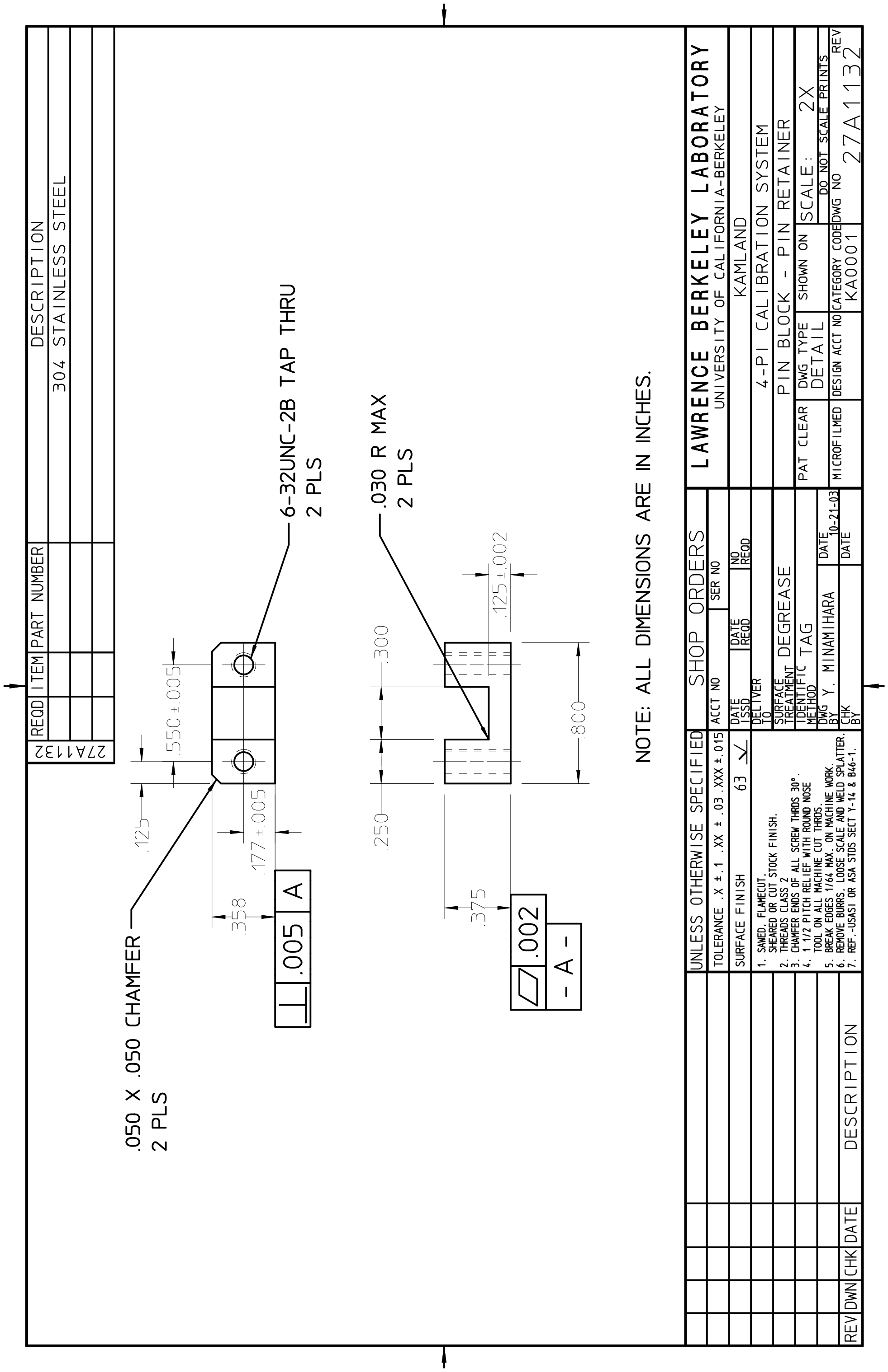


Figure 62: Pin block: pin retainer.

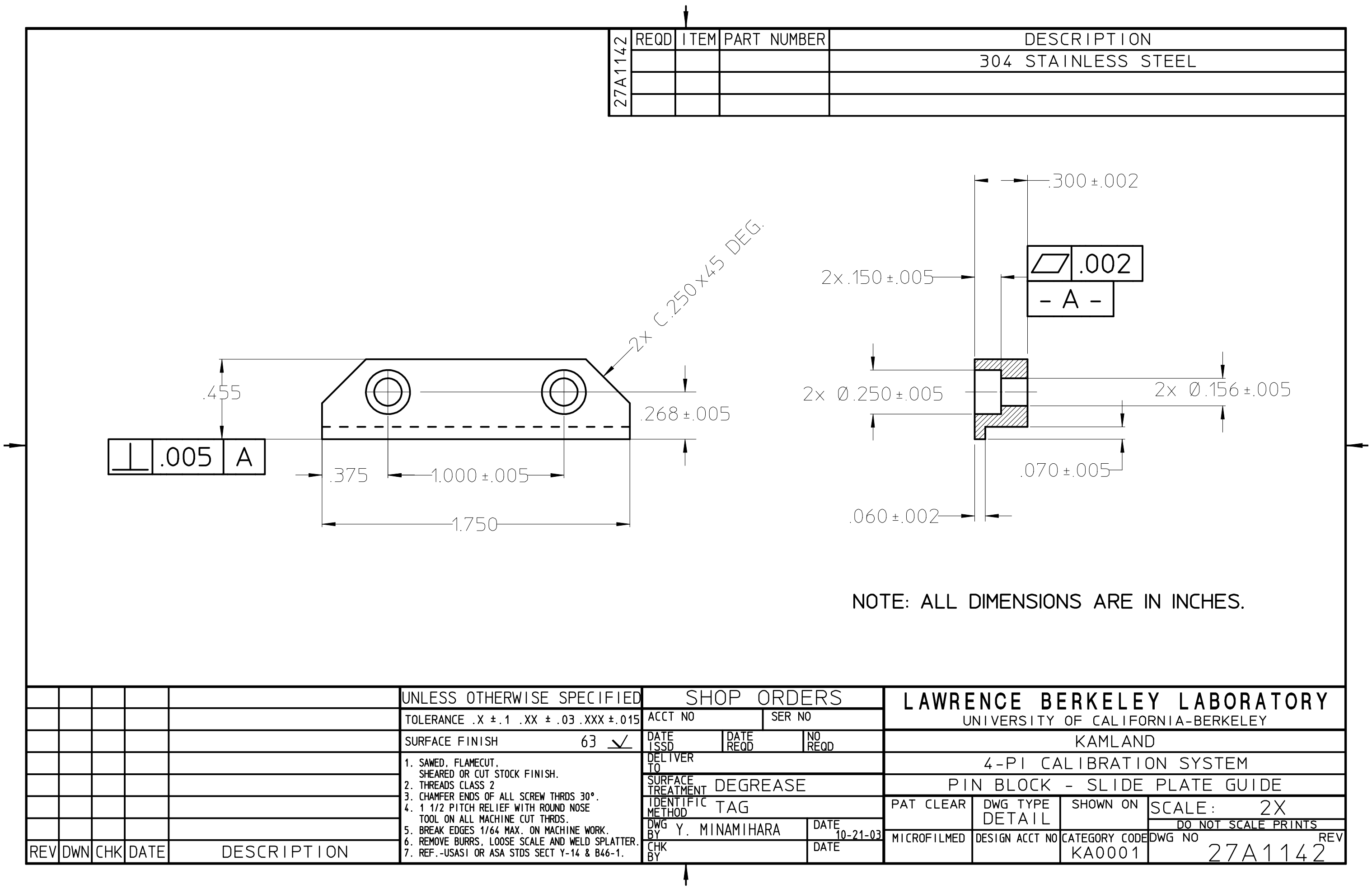


Figure 63: Pin block: slide plate guide.

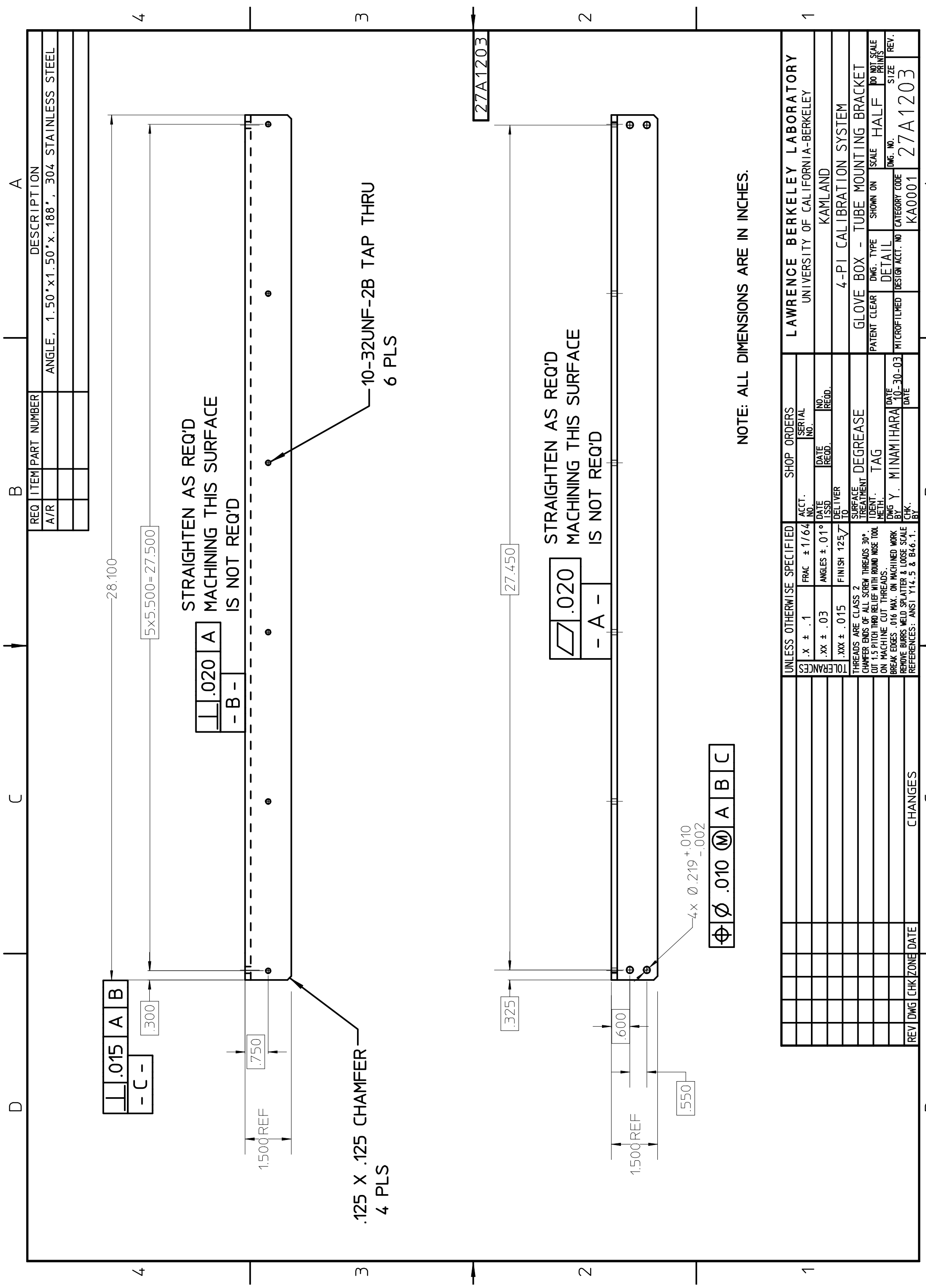


Figure 64: Glove box: tube mounting bracket.

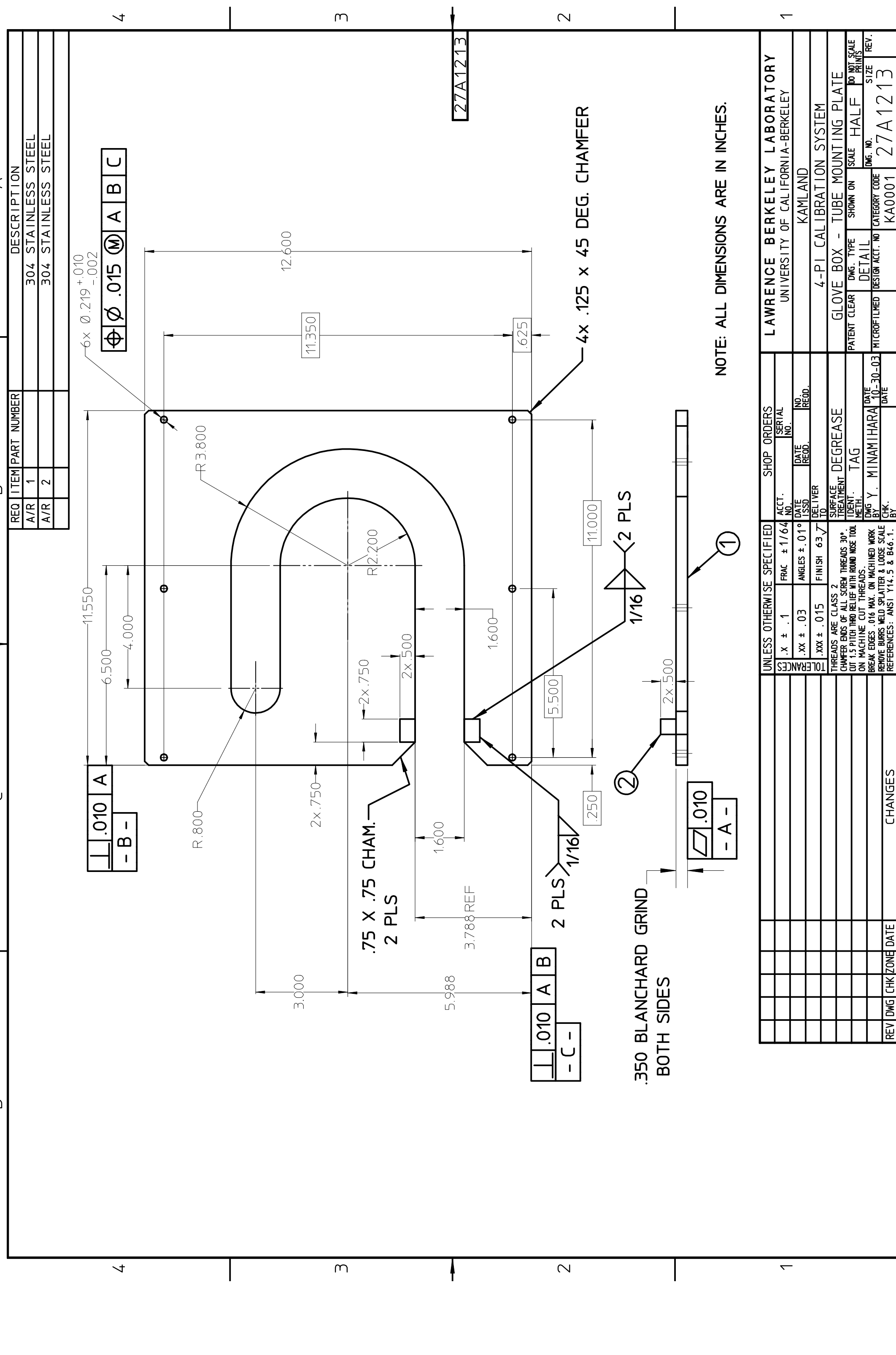


Figure 65: Glove box: tube mounting plate.

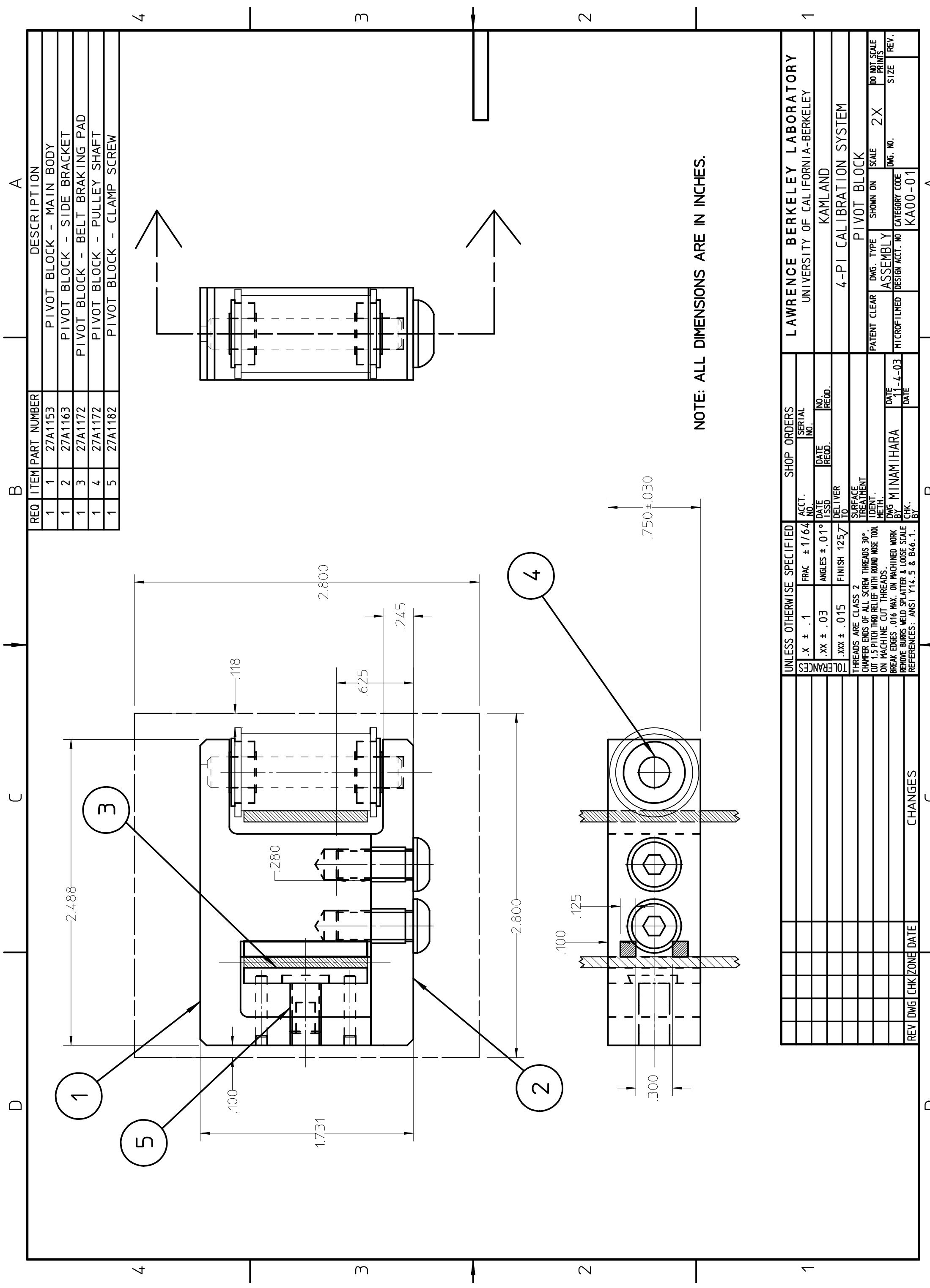


Figure 66: Pivot block.

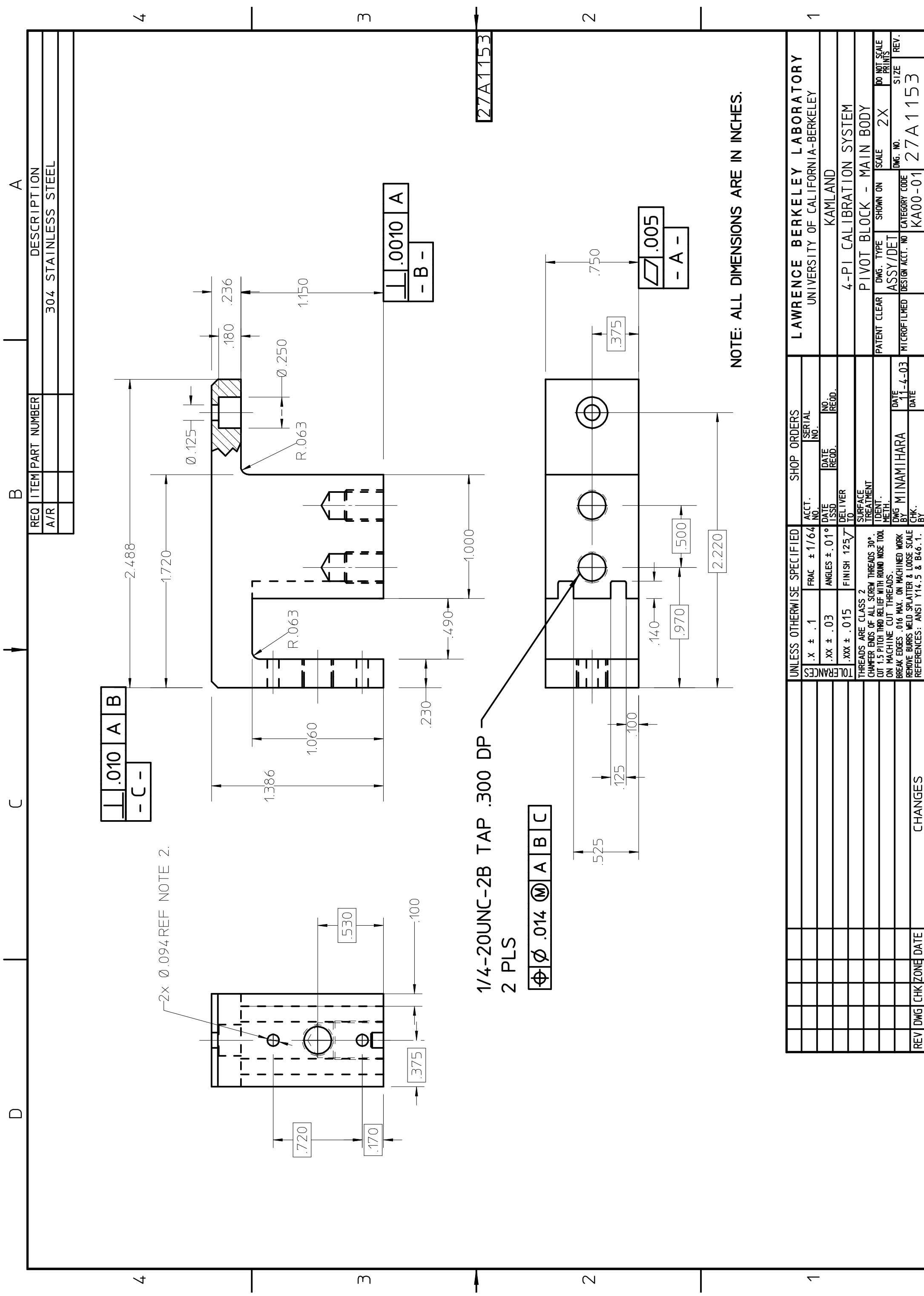


Figure 67: Pivot block: main body.

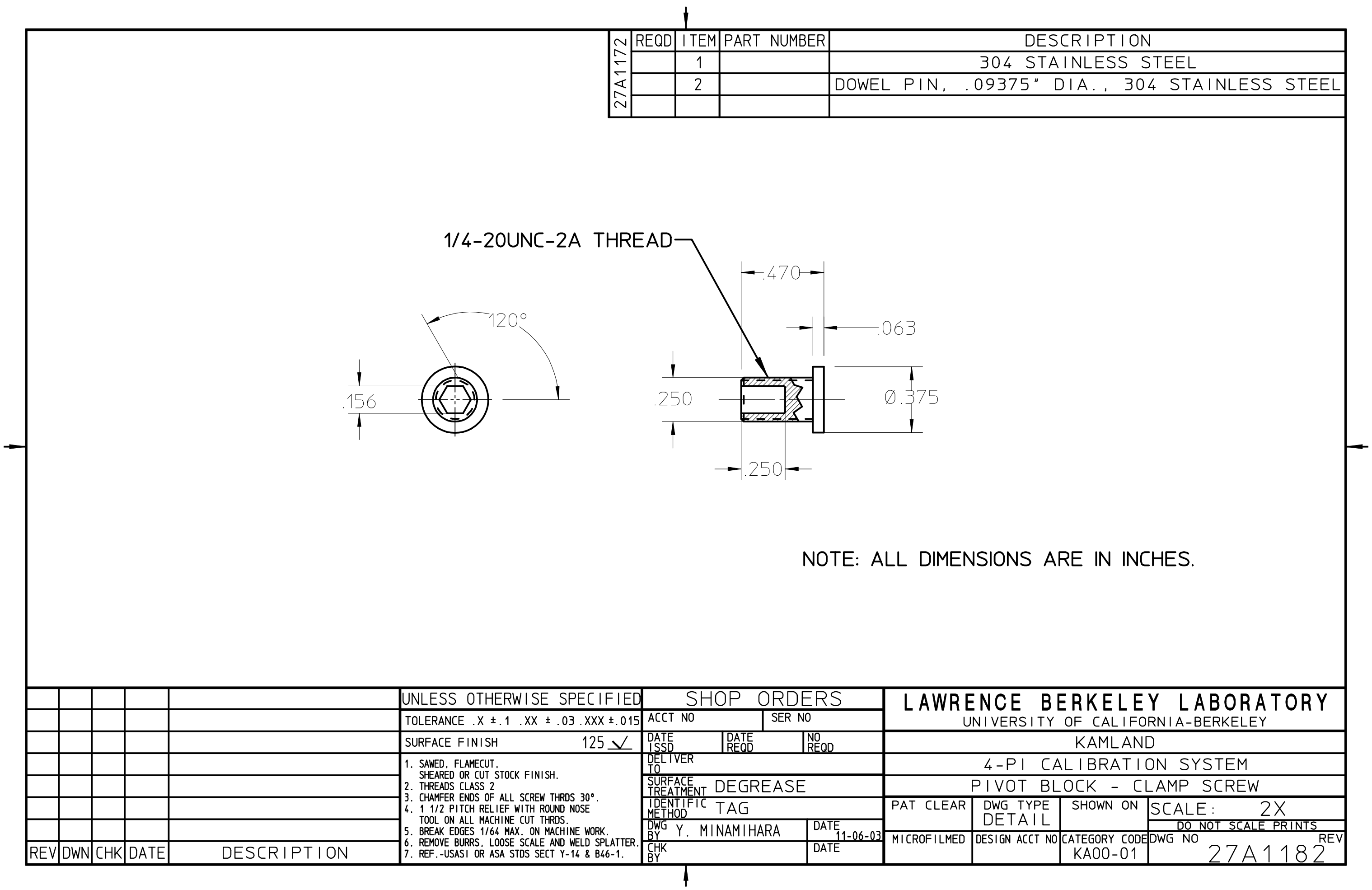


Figure 68: Pivot block: clamp screw.

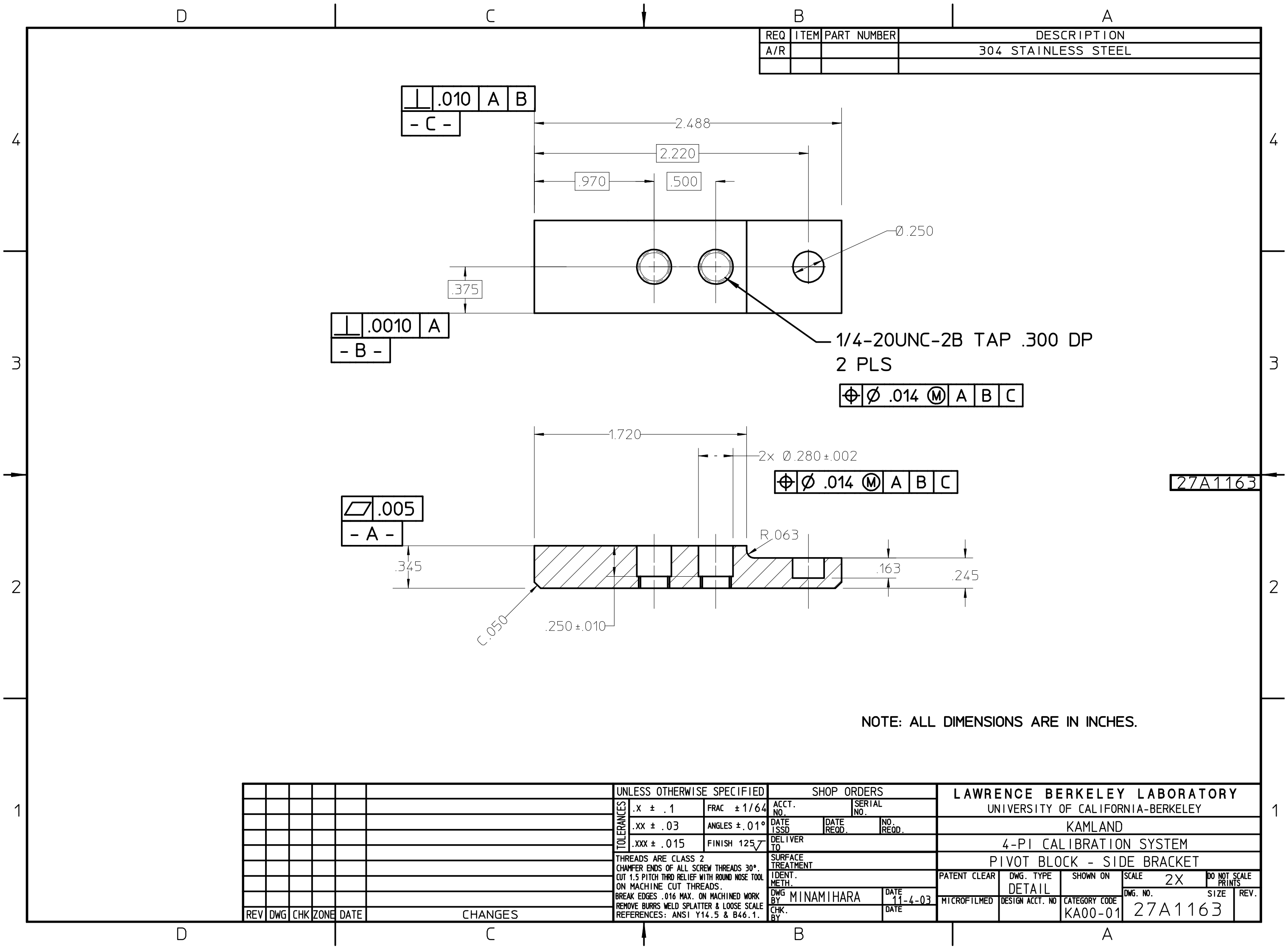


Figure 69: Pivot block: side bracket.

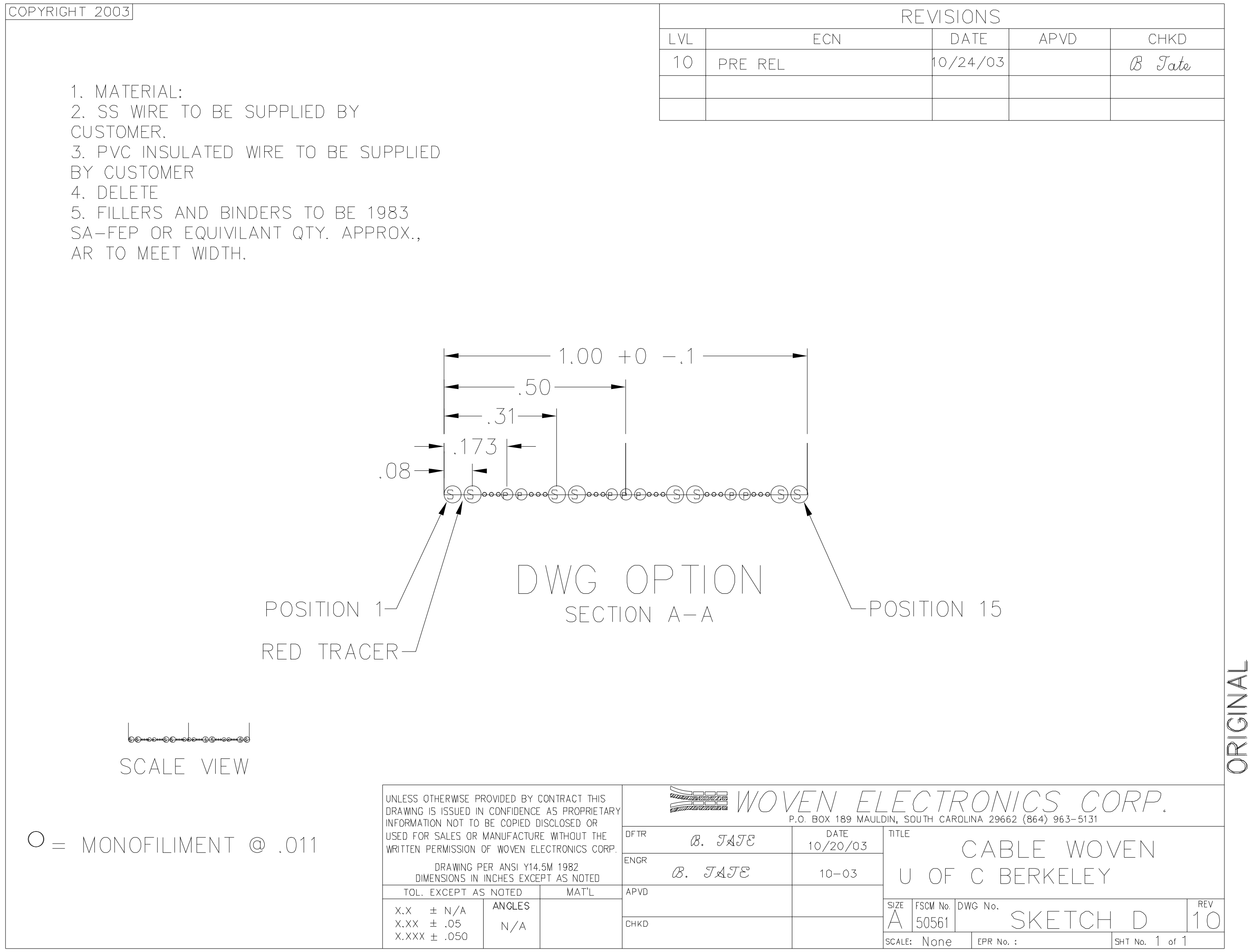


Figure 70: Technical drawing of control cable manufactured by Woven Electronics.

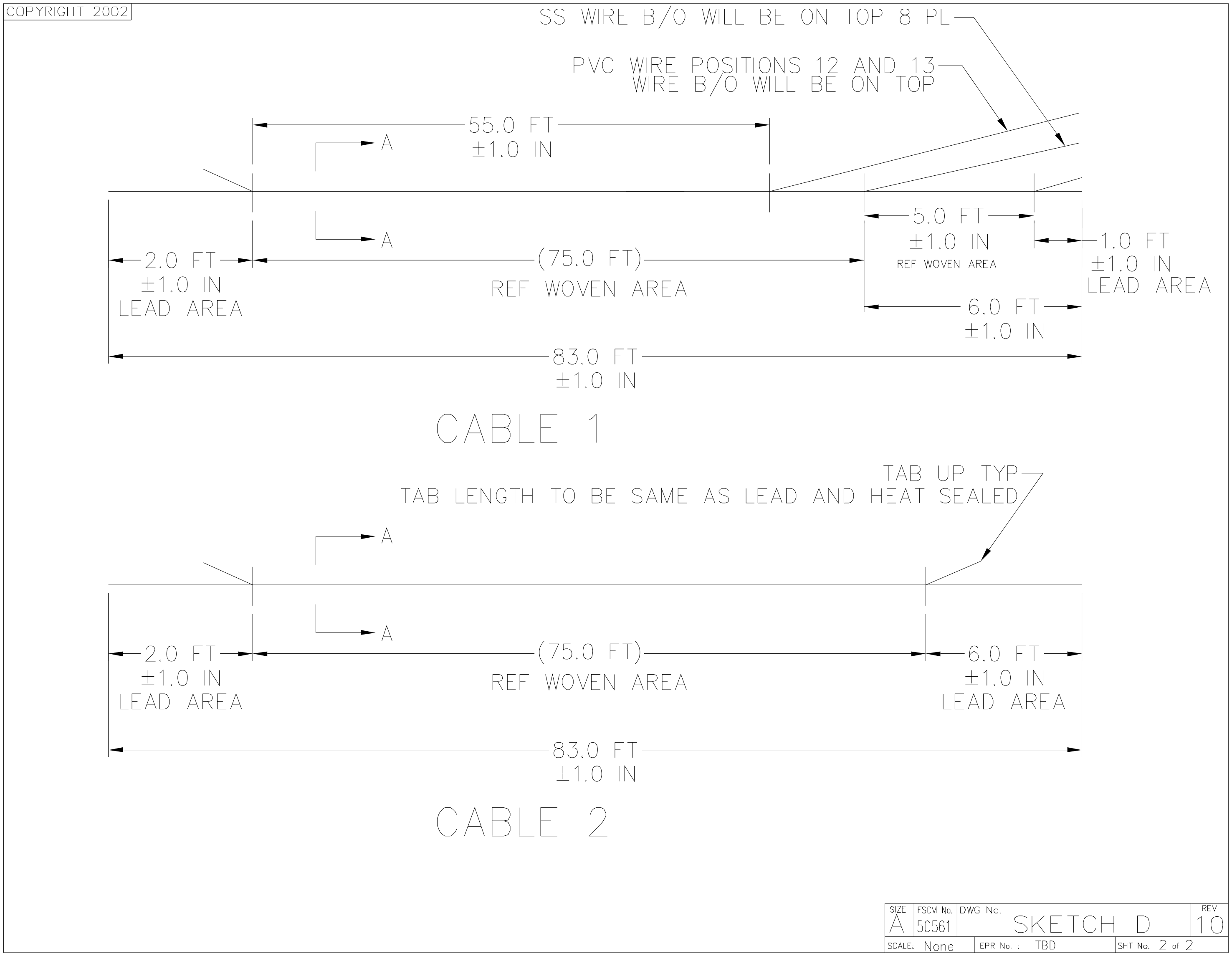


Figure 71: Technical drawing of control cable manufactured by Woven Electronics.